PAPERS

ON

NAVAL ARCHITECTURE,

AND OTHER SUBJECTS CONNECTED WITH

NAVAL SCIENCE.

CONDUCTED BY

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OF

VOLUME III.

PAPERS

ON

NAVAL ARCHITECTURE,

&c.

Art. I.—*On the Displacement of a Ship.*

In the last number of this work we expressed our intention of giving, in succeeding numbers, a series of papers on the different elements of the design of ships; in which, not only the theory of the various branches of the science would be explained, but an example of the necessary calculations would be given in detail. We are aware that such illustrations have been expected in this work, and we hasten to realise those expectations; and we trust that the execution of this intention will render the utility of this work more extensive, by the assistance it will afford to many who are deeply interested in the advancement of this science, but are imperfectly acquainted with its principles and practice. The most complete example of the calculations necessary in the design of a ship yet published, is given in Professor Inman's notes to his translation of Chapman's "*Tractat om Skepps-byggeriet.*" We propose giving a separate paper on each branch of the science, first explaining the general principles on which it rests, and then showing the application of those principles to practice, in the design of a ship: the most correct methods of calculation will be given; and, in some cases, shorter methods of approximation will be shown, which are often of great utility in practice. We shall give, in order, the methods of calculating the displacement, centre of gravity of displacement, centre of gravity of the ship, moment of stability, moment of sails, &c. &c.

No. 1.—*Method of finding the* [1] *Displacement of a Ship.*

By the displacement of a ship is meant, the volume of water it displaces when the ship and water are both at rest.

A floating body displaces a volume of the fluid, whose weight is equal to the weight of the body. The truth of this principle appears from considering, that the vertical pressure of the fluid supports the body, as it previously supported the volume of fluid which it has displaced; and as, in both cases, there is an equilibrium, the vertical pressure of the fluid must support equal weights; that is, the weight of the body is equal to the weight of the volume of the fluid displaced. To obtain, therefore, the total weight of a ship, it is only necessary to ascertain the weight of the volume of water it displaces when it floats at rest; which is found, by calculating the number of cubic feet contained in the part of the body below the line of floatation, and multiplying it by the specific gravity of the water, or the weight of a cubic foot.

Different methods have been given for the determination of the magnitude of the displaced volume, some of which are entitled, by their superior accuracy, to general adoption. As the ship's body, or the displaced volume, is generally an irregular figure, these methods, which determine the areas and solidity of regular figures, give only approximations to its true value; but as the errors of the best methods may be diminished at the will of the calculator to an exceedingly small quantity, they are to be received as practically correct. By the methods now generally used by constructors, the error in the total weight of a ship of three or four thousand tons, is frequently less than half a ton—an error evidently to be totally disregarded in practice.

Atwood, in his disquisition on the stability of ships, in the Philosophical Transactions of the Royal Society for 1798,[2] gives a table, containing eight theorems, for measuring curvilinear spaces; four of them, methods for measuring curvilinear

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[1] A short paper on this subject is given in Vol. I. of this work.

[2] Philosophical Transactions, 1798, Part II., page 260.

spaces terminated by parabolic curves, with 3, 5, 7, or 9 equidistant ordinates, with the correspondent abscissæ, are taken from Stirling's treatise, entitled *Methodus Differentialis;* the four others given by Atwood are for measuring curvilinear spaces with 2, 4, 6, or 8 equi-distant ordinates given, the first terminated by straight lines, the other three by parabolic arcs.

"The methods of approximation to be used for the quadrature of curvilinear spaces, are founded on Sir Isaac Newton's discovery of a theorem, by which, from having given any number of points situated in the same plane, he could ascertain the equation to the curve which would pass through them all; and by means of this equation, was enabled to express the ordinate in the curve, corresponding to an abscissa of any given length, as well as the area intercepted between any two of the ordinates. This discovery the author himself considered amongst his happiest inventions. Amongst the various uses of this theorem, that of determining, by approximation, the areas of curvilinear spaces is not the least considerable; for, by this means, the fluents of fluxional quantities, not discoverable by any known rules of direct investigation, are found to a degree of exactness fully sufficient for any practical purpose, and with very little trouble of computation."

In determining the area of any curvilinear space by the following rules, arcs of parabolic curves of different orders are supposed to pass through the extremities of a certain number of equidistant ordinates, dependent on the order of the parabola; for a conic parabola three ordinates, for a parabola of the third order four ordinates, for a parabola of the fourth order five ordinates, and so on; and as, by taking the distance between these ordinates small, the parabolic arc must very nearly coincide with the given curve passing through the extremities of the same ordinates, the area determined by these rules, which is the true area of the parabolic space, must be very nearly equal to the area of the curvilinear space required.

Table of Areas given by Atwood.

Number of equidistant Ordinates.	Areas.
2	$\frac{A}{2} \times R$
3	$\frac{A+4B}{6} \times R$
4	$\frac{A+3B}{8} \times R$
5	$\frac{7A+32B+12C}{90} \times R$
6	$\frac{19A+75B+50C}{288} \times R$
7	$\frac{41A+216B+27C+272D}{840} \times R$
8	$\frac{36799A+175273B+64827C+146461D}{846720} \times R$
9	$\frac{989A+5888B-928C+10496D-4540E}{28350} \times R$

"In this table the letter A denotes the sum of the first and last ordinate of the number opposite to it in the first column; B is the sum of the second and last but one; C is the sum of the third and last but two, and so on. The extreme letter, suppose D (as in the rule opposite 8 ordinates), is the sum of the two middle ordinates, if the number of ordinates is even; or the extreme letter, suppose D (as in the rule opposite 7 ordinates), is the middle ordinate alone, if the number of ordinates is odd. R is the entire length of the abscissa, which is always equal to the common interval between the ordinates, multiplied by the number of ordinates diminished by unity."

Atwood gives general rules for the first three theorems, which, when the ordinates are numerous, are more readily applied in practice.

Rule 1.

$$\text{Area} = \overline{P - \frac{S}{2}} \times r$$

in which expression P = the sum of all the ordinates; S = the sum of the first and last ordinate; and r = the common distance between the ordinates.

Rule 2.

$$\text{Area} = \overline{S + 4P + 2Q} \times \frac{r}{3}$$

in which expression S = the sum of the first and last ordinate; P = the sum of the 2d, 4th, 6th, &c. ordinate; Q = sum of the 3rd, 5th, 7th, &c. ordinate (the last excepted); and r = the common distance between the ordinates.

Rule 3.

$$\text{Area} = \overline{S + 2P + 3Q} \times \frac{3r}{8}$$

in which expression S = the sum of the first and last ordinate; P = the sum of the 4th, 7th, 10th, &c. ordinate (the last excepted); Q = the sum of the 2d, 3rd, 5th, 6th, 8th, 9th, &c. ordinate; and r = the common distance between the ordinates.

The first rule was formerly in general use, for the calculation of the displacement of a ship, in other countries as well as in this. Bonguer used it in his *Traité du Navire;* and Duhamel du Monceau adopted it afterwards in his *Elemens de l'Architecture Navale.* It is, however, now but little used, from its being much less correct than the two other rules. It supposes straight lines to be drawn from the extremities of the ordinates, and neglects the curvilinear spaces contained between these chords and the corresponding arcs of the curve. It may be used with any number of ordinates. Its proof is very simple.

Let AGG′ A′, Fig. 1, represent any curvilinear space; let the successive ordinates be represented by a, b, c, d, &c.; and let the common interval between the ordinates $= r$. Join AB, BC, CD, &c. Then the area of the trapezium ABB′A′ $=$

$\overline{a+b} \times \frac{r}{2}$; the area of the trapezium BCC′B′ $= \overline{b+c} \times \frac{r}{2}$,

and so on; the whole area, therefore, of AGG′A′ $=$

$$\overline{a+2b+2c+2d+2e+2f+g} \times \frac{r}{2} = \overline{a+b+c+d+e+f+g}$$

$$\overline{-\frac{a+g}{2}} \times r = \overline{P - \frac{S}{2}} \times r.$$

In obtaining an area by this rule, measure, by the scale of the figure, the lengths of all the ordinates; place the lengths of all the ordinates in the first column, and the lengths of the first and last ordinate in the second column; from the sum of the first column subtract half the sum of the second column, and multiply the remainder by the common distance between the ordinates. The result is the approximate value of the area required.

The second rule was first applied to the calculation of the displacement of a ship, and of other elements, by Chapman, in his *Tractat om Skepps-byggeriet;* and is now come into general use. It supposes arcs of a conic parabola to pass through every three successive ordinates, as ABC, CDE, &c. It may be used in all cases in which the number of ordinates is odd; the first area, ABC, having three known ordinates, agreeably to the nature of the curve, and the first of the three ordinates of each succeeding area, as CDE, being the last of the three ordinates of the preceding area.

Let AGG′A′, Fig. 1, represent any curvilinear area, and let the ordinates, and common distance between them, be represented as in the proof of the first rule. Let ABC be an arc of a conic parabola, whose axis is perpendicular to A′C′, and let the space ABC be supposed to be generated by the straight line HI moving in the direction BK. Let HI $= y$, and BL $= x$; then $y^2 = px$, (p being the parameter of the parabola.)

Then $\int y\,dx = \int \frac{2y^2\,dy}{p}.\ sin.\ \angle\ \mathrm{KLM} = \frac{2y^3}{3p}.\ sin.\ \angle\ \mathrm{L} +$

correction $= \frac{2xy}{3p}$. *sin.* L + correction = the area HBI. The correction = o, because when $x = o$, both quantities vanish. The whole area ABC is therefore $= \frac{2}{3}$ BK. AC. *sin.* $\angle$ L $= \frac{2}{3}$ BK. AN $= \frac{2}{3}.\overline{b - \frac{a+c}{2}}.\ 2r = \overline{4b - 2a - 2c}.\frac{r}{3}$.
Add to this the area of the trapezium A′ACC′ $= \overline{a + c}.\ r$.
Then the whole area A′ABCC′ $= \overline{4b - 2a - 2c}.\frac{r}{3} + \overline{a + c}.\ r = \overline{a + 4b + c}.\frac{r}{3}$. In the same manner the area C′CDEE′ $= \overline{c + 4d + e}.\frac{r}{3}$; and so on. The whole area AGG′A′, therefore $= \overline{a + 4b + 2c + 4d + 2e + 4f + g}.\frac{r}{3} = \overline{S + 4P + 2Q}.\frac{r}{3}$.

In obtaining an area by this rule, place the lengths of the ordinates in three columns; in the first column the lengths of the first and last ordinate; in the second column the lengths of the 2d, 4th, 6th, &c., ordinate; and in the third column the lengths of the 3rd, 5th, 7th, &c., ordinate, the last ordinate excepted; multiply the sum of the second column by 4, and the sum of the third column by two, and to the sum of these products add the sum of the first column; multiply the sum by one third the common distance between the ordinates, and the result is the approximate value of the area required.

The third rule was first applied to the calculation of the elements of ships by Atwood. It supposes arcs of a cubic parabola to pass through every four successive ordinates, as ABCD, DEFG, Fig. 1. It is applicable to all cases in which the number of the ordinates is a multiple of 3 + 1: the first area, ABCD, having four ordinates known, agreeably to the nature of the curve, and the first of the four ordinates of each succeeding area, as DEFG, being the last of the four ordinates of the preceeding area, as ABCD.

Let the same notation be observed as in the proof of the se-

cond rule; take the equation of the parabola of the third degree, $y = P + Qx + Rx^2 + Sx^3$.

$$\begin{aligned} \text{When } x &= o, & a &= P \\ x &= r, & b &= P + Qr + Rr^2 + Sr^3 \\ x &= 2r, & c &= P + 2Qr + 4Rr^2 + 8Sr^3 \\ x &= 3r, & d &= P + 3Qr + 9Rr^2 + 27Sr^3 \end{aligned}$$

From these four independent equations, the coefficients of the equation of the curve, P, Q, R, and S, may be immediately found in terms of the known ordinates, *a*, *b*, *c*, and *d*.

$$\text{Hence } P = a$$

$$Q = \frac{18b - 11a - 9c + 2d}{6r}$$

$$R = \frac{2a - 5b + 4c - d}{2r^2}$$

$$S = \frac{3b - a - 3c + d}{6r^3}$$

Substituting these values of the coefficients in the equation $y = P + Qx + Rx^2 + Sx^3$; it becomes

$$y = a + \frac{18b - 11a - 9c + 2d}{6r} . x + \frac{2a - 5b + 4c - d}{2r^2} . x^2 + \frac{3b - a - 3c + d}{6r^3} . x^3. \text{ and } \int y\,dx = \int a\,dx +$$

$$\int \frac{18b - 11a - 9c + 2d}{6r} . x\,dx + \int \frac{2a - 5b + 4c - d}{2r^2} . x^2\,dx + \int \frac{3b - a - 3c + d}{6r^3} . x^3\,dx = ax +$$

$$\frac{18b - 11a - 9c + 2d}{12r} . x^2 + \frac{2a - 5b + 4c - d}{6r^2} . x^3 + \frac{3b - a - 3c + d}{24r^3} . x^4 + \text{correction.} = \text{the parabolic area.}$$

The correction $= o$, because when $x = o$, the quantities vanish.

Taking $x = 3r$, and substituting accordingly, the area

$$A'ABCDD' = \overline{a + 3b + 3c + d} . \frac{3}{8} r.$$

In the same manner, the area D′DEFGG′ $= \overline{d+3e+3f+g}.\frac{3}{8}r.$
The whole area AGG′A′, therefore,
$$=\overline{a+3b+3c+2d+3e+3f+g}.\frac{3}{8}r=\overline{S+2P+3Q}.\frac{3}{8}r.$$

In obtaining an area by this rule, place the lengths of the ordinates in three columns; in the first column the lengths of the first and last ordinate; in the second column the lengths of the 4th, 7th, 10th, &c. ordinate, the last excepted; and in the third column the lengths of the 2d, 3rd, 5th, 6th, 8th, &c., ordinate; multiply the sum of the second column by 2, and the sum of the third column by 3, and to the sum of these products add the sum of the first column; multiply the sum by three-eighths of the common distance between the ordinates, and the result is the approximate value of the area required.

In order to find the displacement of a ship by means of these rules, it is necessary to have the sheer and body plans of the ship. Let ABCD, Fig. 2, represent the sheer draught of the ship, DE the loadwater-line, to which the displacement is to be calculated. Take any point F within a few feet from the stem, and any point G on the same line near the stern-post; divide the distance FG into such a number of equal parts, at 2, 3, 4, 5, 6, &c., the common distance between them being from four to six feet, that the number of the points of division together with the extreme points, F and G, may be either odd, or a multiple of 3+1. Through these points, draw 11, 22, 33, 44, 55, &c., perpendicular to DE. Let H*h*H, Fig. 3, represent the body plan of the ship, the lines marked, 11, 22, 33, 44, 55, &c., being the transverse vertical sections of the ship, to the outside of the plank, at the corresponding stations 1, 2, 3, 4, 5, &c., in the sheer draught, Fig. 2; those on the right side, being the vertical sections before the midship section, and those on the left side, the vertical sections abaft the midship section. Draw the straight lines 22, 33, 44, &c., below the loadwater line DE and parallel to it, at the distance of one foot apart (or further apart, if any case may render it necessary to prefer greater expedition to greater accuracy), in both the sheer and body plans. Then measure by the scale of the drawings, the lengths from the

middle line Ih, of the half breadths on these horizontal lines of all the sections in the body plan; and insert them in a table of ordinates. See table of ordinates of the Volage, page 12.

The areas of these vertical sections are then obtained by means of either of the preceding rules, the second or third rule being always to be preferred, from their greater accuracy. This will give the vertical areas between the loadwater line and the lowest horizontal line, to which must be added, the small areas below this line, including the remainder of the curvilinear areas of the section, with the areas of the sections of the keel and false keel. The half-vertical sections are then found, from 1 or F to the last at 22 or G; and by using these areas as ordinates in one of the rules, the half-displacement is found between the foremost section Ff, and the aftermost section Gg. The solids before the foremost, and abaft the aftermost, section, are then obtained separately, by calculating the small horizontal areas at the extremities, and using them as ordinates in one of the rules; the small solids below the lowest horizontal line, and before the foremost and abaft the aftermost sections being added to them. By adding together these three solids, the half-displacement is obtained, by means of the vertical sections.

The displacement may then be found by means of the horizontal sections: both methods being generally adopted, as a check to the correctness of the calculations. The half-areas of the horizontal sections are obtained by first calculating the areas by one of the rules, between the foremost and aftermost sections, Ff and Gg, and then adding to them the small horizontal sections before and abaft these vertical sections. By using these areas as ordinates in one of the rules, the solid is found between the loadwater section and the lowest horizontal section; and by adding to it the solid below this section, calculated separately, the half-displacement is obtained by means of the horizontal sections.

By dividing the displacement thus obtained in cubic feet by 35, the number of cubic feet of sea water in a ton, the displacement of the ship is given in tons.

The following example of the calculation of the displacement of the Volage, both by vertical and horizontal sections, will illustrate what has been said on the subject.

		feet.
Length at the loadwater line from the fore part of the rabbet of the stem, to the after part of the rabbet of the stern-post		115,4
Breadth at the loadwater line to the outside of plank		32,2
Draught of water to the under side of the false keel	forward .	14,8
	abaft . .	15,8
Depth of the keel and false keel below the lower edge of the rabbet of the keel		1,7

The number of vertical sections in this example is 22, the common distance between them being 5 feet; and the number of horizontal sections is 7, the common distance between them being one foot.

Table of Ordinates.

	1	2	3	4	5	6	7	8	9	10	11	12	13
1	3.85	9.75	12.05	13.5	14.3	14.92	15.5	15.72	15.9	16.04	16.07	16.1	16.1
2	2.7	7.7	10.85	12.8	13.85	14.65	15.25	15.5	15.8	15.93	16.0	16.05	16.06
3	2.1	6.08	9.5	11.85	13.2	14.2	14.9	15.22	15.6	15.75	15.84	15.9	15.95
4	1.72	4.7	7.95	10.65	12.3	13.6	14.4	14.8	15.25	15.4	15.55	15.7	15.75
5	1.42	3.68	6.42	9.1	11.25	12.7	13.65	14.2	14.75	15.0	15.15	15.32	15.48
6	1.22	2.95	5.12	7.45	9.8	11.5	12.6	13.35	14.05	14.4	14.62	14.8	14.98
7	1.03	2.38	4.05	5.95	8.08	10.08	11.3	12.25	13.05	13.55	13.9	14.1	14.22
8	.9	1.92	3.25	4.65	6.55	8.4	9.9	11.0	11.7	12.45	12.85	13.12	13.18
9	.78	1.55	2.55	3.62	5.15	6.88	8.25	9.4	10.25	11.0	11.55	11.75	11.8
10	.68	1.25	2.0	2.85	3.9	5.22	6.5	7.62	8.5	9.22	9.85	10.1	10.05
11	.6	1.02	1.62	2.3	3.0	3.95	4.85	5.78	6.5	7.1	7.7	8.0	7.96
12	.53	.8	1.26	1.8	2.28	2.7	3.4	4.0	4.4	4.8	5.1	5.4	5.45
13	.48	.65	1.0	1.35	1.6	1.75	2.15	2.45	2.55	2.75	2.9	3.0	2.95
Areas below section No. 13.	1.68	1.92	2.33	2.75	2.99	3.01	3.4	3.5	3.53	3.65	3.85	3.82	3.63
Half-areas of vertical sections.	17.4	40.98	63.36	83.17	102.87	115.29	127.32	135.82	142.73	147.8	151.6	153.79	154.25

Table of Ordinates (continued).

	14	15	16	17	18	19	20	21	22	Small areas before No. 1.	Small areas abaft No. 22.	Half-areas of water sections.
1	16.1	16.1	16.1	16.05	16.0	15.8	15.5	14.6	12.25	6.18	63.38	1624.61
2	16.07	16.08	16.03	15.9	15.8	15.52	15.05	13.92	11.25	4.87	54.48	1572.08
3	15.98	15.92	15.88	15.7	15.5	15.1	14.32	13.0	10.05	4.22	44.87	1509.51
4	15.8	15.72	15.65	15.35	15.09	14.45	13.45	11.88	8.65	3.87	35.85	1435.45
5	15.48	15.3	15.2	14.8	14.4	13.7	12.45	10.5	7.2	3.6	27.63	1347.63
6	14.92	14.7	14.6	14.1	13.64	12.7	11.2	9.08	5.88	3.46	20.33	1246.38
7	14.12	13.9	13.8	13.2	12.55	11.52	9.88	7.65	4.6	3.34	15.48	1132.34
8	13.1	12.9	12.78	12.1	11.32	10.2	8.3	6.15	3.4	3.26	10.06	1004.44
9	11.82	11.65	11.5	10.7	9.85	8.75	6.72	4.75	2.3	3.21	6.51	865.9
10	10.04	9.95	9.8	9.0	8.1	6.95	5.0	3.38	1.45	3.12	4.17	709.66
11	7.9	7.88	7.7	6.9	6.05	5.0	3.45	2.3	.85	3.06	2.72	544.69
12	5.35	5.15	5.0	4.4	3.75	3.1	2.2	1.45	.5	3.02	2.27	366.88
13	2.7	2.6	2.48	2.28	2.0	1.7	1.25	.88	.4	2.91	1.7	211.74
Areas below section No. 13.	3.34	3.16	3.03	2.88	2.67	2.39	2.03	1.6	1.12	9.37	2.55	316.4
Half-areas of vertical sections.	153.56	151.88	150.46	144.34	137.82	128.22	112.46	93.38	63.49	52.81	258.56	

In the following calculations for determining the half-areas of the vertical sections, the third rule $\overline{S+2P+3Q}\times\frac{3}{8}r$ is used, the number of ordinates, 13, being a multiple of 3, +1. The second rule might with equal propriety be used in this case, as the number of ordinates is odd. The common distance r, between the ordinates, being, in these calculations, one foot, it is only necessary to multiply by 3, and divide by 8. When the area between the ordinates 1 and 13 is found by the rule, which in vertical section 1, = 15.72, the small area below the ordinate 13 is calculated separately, equal in this case to 1.68, and is added to it, giving the complete half-area of the vertical section 1 = 17.4 feet.

Half-areas of Vertical Sections.

No. 1.

1..3.85	4.. 1.72	2.. 2.70
13.. .48	7.. 1.03	3.. 2.10
	10.. .68	5.. 1.42
4.33		6.. 1.22
	3.43	8.. .90
	2	9.. .78
		11.. .60
	6.86	12.. .53
	4.33	
	30.75	10.25
		3
	41.94	
	3	30.75
	8)125.82	
	15.72	
Area below ordinate 13	1.68	
Half-area of vertical section ..	17.40	

No. 2.

1..9.75	4.. 4.70	2.. 7.70
13.. .65	7.. 2.38	3.. 6.08
	10.. 1.25	5.. 3.68
10.40		6.. 2.95
	8.33	8.. 1.92
	2	9.. 1.55
		11.. 1.02
	16.66	12.. .80
	10.40	
	77.10	25.70
		3
	104.16	
	3	77.10
	8)312.48	
	39.06	
Area below ordinate 13	1.92	
Half-area of vertical section ..	40.98	

Half-areas of Vertical Sections.

No. 3.

1..12.05	4.. 7.95	2..10.85
13.. 1.00	7.. 4.05	3.. 9.50
	10.. 2.00	5.. 6.42
13.05		6.. 5.12
	14.00	8.. 3.25
	2	9.. 2.55
		11. 1.62
	28.00	12.. 1.26
	13.05	
	121.71	40.57
		3
	162.76	
	3	121.71
	8)488.28	
	61.03	
Area below ordinate 13	2.33	
Half-area of vertical section ..	63.36	

No. 4.

1..13.50	4..10.65	2..12.80
13.. 1.35	7.. 5.95	3..11.85
	10.. 2.85	5.. 9.10
14.85		6.. 7.45
	19.45	8.. 4.65
	2	9.. 3.62
		11.. 2.30
	38.90	12.. 1.80
	14.85	
	160.71	53.57
		3
	214.46	
	3	160.71
	8)643.38	
	80.42	
Area below ordinate 13	2.75	
Half-area of vertical section ..	83.17	

No. 5.

1..14.3	4..12.30	2..13.85
13.. 1.6	7.. 8.08	3..13.20
	10.. 3.90	5..11.25
15.9		6.. 9.80
	24.28	8.. 6.55
	2	9.. 5.15
		11.. 3.00
	48.56	12.. 2.28
	15.9	
	195.24	65.08
		3
	259.70	
	3	195.24
	8)779.10	
	99.88	
Area below ordinate 13	2.99	
Half-area of vertical section ..	102.87	

No. 6.

1..14.92	4..13.60	2..14.65
13.. 1.75	7..10.08	3..14.20
	10.. 5.22	5..12.70
16.67		6..11.50
	28.90	8.. 8.40
	2	9.. 6.88
		11.. 3.95
	57.80	12.. 2.70
	16.67	
	224.94	74.98
		3
	299.41	
	3	224.94
	8)898.23	
	112.28	
Area below ordinate 13	3.01	
Half-area of vertical section ..	115.29	

Half-areas of Vertical Sections.

No. 7.

1..15.50	4..14.4	2..15.25
13.. 2.15	7..11.3	3..14.90
	10.. 6.5	5..13.65
17.65		6..12.60
	32.2	8.. 9.90
	2	9.. 8.25
		11.. 4.85
	64.4	12.. 3.40
	17.65	
	248.4	82.80
		3
	330.45	
	3	248.40
	8)991.35	
	123.92	
Area below ordinate 13	3.40	
Half-area of vertical section ..	127.32	

No. 8.

1..15.72	4..14.80	2..15.50
13.. 2.45	7..12.25	3..15.22
	10.. 7.62	5..14.20
18.17		6..13.35
	34.67	8..11.00
	2	9.. 9.40
		11.. 5.78
	69.34	12.. 4.00
	18.17	
	265.35	88.45
		3
	352.86	
	3	265.35
	8)1058.58	
	132.32	
Area below ordinate 13	3.50	
Half-area of vertical section ..	135.82	

No. 9.

1..15.90	4..15.25	2..15.80
13.. 2.55	7..13.05	3..15.60
	10.. 8.50	5..14.75
18.45		6..14.05
	36.80	8..11.70
	2	9..10.25
		11.. 6.50
	73.60	12.. 4.40
	18.45	
	279.15	93.05
		3
	371.20	
	3	279.15
	8)1113.60	
	139.20	
Area below ordinate 13	3.53	
Half-area of vertical section ..	142.73	

No. 10.

1..16.04	4..15.40	2..15.93
13.. 2.75	7..13.55	3..15.75
	10.. 9.22	5..15.00
18.79		6..14.00
	38.17	8..12.45
	2	9..11.00
		11.. 7.10
	76.34	12.. 4.80
	18.79	
	289.29	96.43
		3
	384.42	
	3	289.29
	8)1153.26	
	144.15	
Area below ordinate 13	3.65	
Half-area of vertical section ..	147.80	

Half-areas of Vertical Sections.

No. 11.

	1..16.07	4..15.55	2..16.00
	13.. 2.90	7..13.90	3..15.84
		10.. 9.85	5..15.15
	18.97		6..14.62
		39.30	8..12.85
		2	9..11.55
			11.. 7.70
		78.60	12.. 5.10
		18.97	
		296.43	98.81
			3
		394.00	
		3	296.43
		8)1182.00	
		147.75	
Area below ordinate 13		3.85	
Half-area of vertical section ..		151.60	

No. 12.

	1..16.1	4..15.7	2..16.05
	13.. 3.0	7..14.1	3..15.90
		10..10.1	5..15.32
	19.1		6..14.80
		39.9	8..13.12
		2	9..11.75
			11.. 8.00
		79.80	12.. 5.40
		19.10	
		301.02	100.34
			3
		399.92	
		3	301.02
		8)1199.76	
		149.97	
Area below ordinate 13		3.82	
Half-area of vertical section ..		153.79	

No. 13.

	1..16.10	4..15.75	2..16.06
	13.. 2.95	7..14.22	3..15.95
		10..10.05	5..15.48
	19.05		6..14.98
		40.02	8..13.18
		2	9..11.80
			11.. 7.96
		80.04	12.. 5.45
		19.05	
		302.58	100.86
			3
		401.67	
		3	302.58
		8)1205.01	
		150.62	
Area below ordinate 13		3.63	
Half-area of vertical section ..		154.25	
		2	
Area of midship section ..		308.50	

No. 14.

	1..16.1	4..15.80	2..16.07
	13.. 2.7	7..14.12	3..15.98
		10..10.04	5..15.48
	18.8		6..14.92
		39.96	8..13.10
		2	9..11.82
			11.. 7.90
		79.92	12.. 5.35
		18.80	
		301.86	100.62
			3
		400.58	
		3	301.86
		)1201.74	
		150.22	
Area below ordinate 13		3.34	
Half-area of vertical section ..		153.56	

Half-areas of Vertical Sections.

No. 15.

1..16.1	4..15.72	2..16.08
13.. 2.6	7..13.90	3..15.92
	10.. 9.95	5..15.30
18.7		6..14.70
	39.57	8..12.90
	2	9..11.65
		11.. 7.88
	79.14	12.. 5.15
	18.70	
	298.74	99.58
		3
	396.58	
	3	298.74
	8)1189.74	
	148.72	
Area below ordinate 13	3.16	
Half-area of vertical section	151.88	

No. 16.

1..16.10	4..15.65	2..16.03
13.. 2.48	7..13.80	3..15.88
	10.. 9.80	5..15.20
18.58		6..14.60
	39.25	8..12.78
	2	9..15.50
		11.. 7.70
	78.50	12.. 5.00
	18.58	
	296.07	98.69
		3
	393.15	
	3	296.07
	8)1179.45	
	147.43	
Area below ordinate 13	3.03	
Half-area of vertical section	150.46	

No. 17.

1..16.05	4..15.35	2..15.9
13.. 2.28	7..13.20	3..15.7
	10.. 9.00	5..14.8
18.33		6..14.1
	37.55	8..12.1
	2	9..10.7
		11.. 6.9
	75.10	12.. 4.4
	18.33	
	283.80	94.6
		3
	377.23	
	3	283.8
	8)1131.69	
	141.46	
Area below ordinate 13	2.88	
Half-area of vertical section	144.34	

No. 18.

1..16.0	4..15.09	2..15.80
13.. 2.0	7..12.55	3..15.50
	10.. 8.10	5..14.40
18.0		6..13.64
	35.74	8..11.32
	2	9.. 9.85
		11.. 6.05
	71.48	12.. 3.75
	18.00	
	270.93	90.31
		3
	360.41	
	3	270.93
	8)1081.23	
	135.15	
Area below ordinate 13	2.67	
Half-area of vertical section	137.82	

Half-areas of Vertical Sections.

No. 19.

1..15.8	4..14.45	2..15.52
13.. 1.7	7..11.52	3..15.10
	10.. 6.95	5..13.70
17.5		6..12.70
	32.92	8..10.20
	2	9.. 8.75
		11.. 5.00
	65.84	12.. 3.10
	17.50	
	252.21	84.07
		3
	335.55	
	3	252.21
	8)1006.65	
	125.83	
Area below ordinate 13	2.39	
Half-area of vertical section	128.22	

No. 20.

1..15.50	4..13.45	2..15.05
13.. 1.25	7.. 9.88	3..14.32
	10.. 5.00	5..12.45
16.75		6..11.20
	28.33	8.. 8.30
	2	9.. 6.72
		11.. 3.45
	56.66	12.. 2.20
	16.75	
	221.07	73.69
		3
	294.48	
	3	221.07
	8)883.44	
	110.43	
Area below ordinate 13	2.03	
Half-area of vertical section	112.46	

No. 21.

1..14.60	4..11.88	2..13.92
13.. .88	7.. 7.65	3..13.00
	10.. 3.38	5..10.50
15.48		6.. 9.08
	22.91	8.. 6.15
	2	9.. 4.75
		11.. 2.30
	45.82	12.. 1.45
	15.48	
	183.45	61.15
		3
	244.75	
	3	183.45
	8)734.25	
	91.78	
Area below ordinate 13	1.60	
Half-area of vertical section	93.38	

No. 22.

1..12.25	4.. 8.65	2..11.25
13.. .40	7.. 4.60	3..10.05
	10.. 1.45	5.. 7.20
12.65		6.. 5.88
	14.70	8.. 3.40
	2	9.. 2.30
		11.. .85
	29.40	12.. .50
	12.65	
	124.29	41.43
		3
	166.34	
	3	124.29
	8)499.02	
	62.37	
Area below ordinate 13	1.12	
Half-area of vertical section	63.49	

Solids before Vertical Section 1, *and abaft Vertical Section* 13.

Solid forward.

1..63.38	4..35.85	2..54.48
13.. 1.70	7..15.48	3..44.87
	10.. 4.17	5..27.63
65.08		6..20.33
	55.50	8..10.06
	2	9.. 6.51
		11.. 2.72
	111.00	12.. 2.27
	65.08	
	506.61	168.87
		3
	682.69	
	3	506.61
	8)2048.07	
	256.01	
Solid below horizontal section 13	2.55	
Half-solid forward	258.56	

Solid abaft.

1..6.18	4..3.87	2..4.87
13..2.91	7..3.34	3..4.22
	10..3.12	5..3.60
9.09		6..3.46
	10.33	8..3.26
	2	9..3.21
		11..3.06
	20.66	12..3.02
	9.09	
	86.10	28.70
		3
	115.85	
	3	86.10
	8)347.55	
	43.44	
Solid below horizontal section 13	9.37	
Half-solid abaft	52.81	

Displacement found by means of the Areas of the Vertical Sections.

1..17.40	4.. 83.17	2.. 40.98
22..63.49	7..127.32	3.. 63.36
	10..147.80	5..102.87
80.89	13..154.25	6..115.29
	16..150.46	8..135.82
	19..128.22	9..142.73
		11..151.60
	791.22	12..153.79
	2	14..153.56
		15..151.88
	1582.44	17..144.34
	80.89	18..137.82
	5099.64	20..112.46
		21.. 93.38
	6762.97	
	15	1699.88
		3
	3381485	
	676297	5099.64
	8)101445.55	
	12680.57	
Solid forward	258.56	
Solid abaft	52.81	
Half displacement in cubic feet ..	12991.94	
	2	
Whole displacement in cubic feet ..	25983.88	÷35 = 742.39 whole displacement in tons.

In the last calculation, the quantity 6762.97 is multiplied by 15, because r, the distance between the vertical sections, is 5 feet, so that $3r = 15$.

It is usual to find the Displacement also by means of the horizontal sections, to ensure correctness.

Half-area of the Loadwater Section.

	1.. 3.85	4..13.50	2.. 9.75
	22..12.25	7..15.50	3..12.05
		10..16.04	5..14.30
	16.10	13..16.10	6..19.92
		16..16.10	8..15.72
		19..15.80	9..15.90
			11..16.07
		93.04	12..16.10
		2	14..16.10
			15..16.10
		186.08	17..16.05
		16.10	18..16.00
		627.18	20..15.50
			21..14.60
		829.36	
		15	209.06
			3
		414680	
		82936	627.18
		8)12440.40	
		1555.05	
Area before vertical section No. 1 ...		6.18	
Area abaft vertical section No. 22 ..		63.38	
Half-area of loadwater section		1624.61	
		2	
Area of loadwater section		3249.22	

In the same manner the areas of the other horizontal sections are found. The half-areas of all these sections are given in the last column of the table of ordinates.

Displacement found by means of the Areas of the Horizontal Sections.

	1..1624.61	4..1435.45	2..1572.08
	13.. 211.74	7..1132.34	3..1509.51
		10.. 709.66	5..1347.63
	1836.35		6..1246.38
		3277.45	8..1004.44
		2	9.. 865.90
			11.. 544.69
		6554.90	12.. 366.88
		1836.35	
		25372.53	8457.51
			3
		33763.78	
		3	25372.53
		8)101291.34	
		12661.41	
Solid below section No. 13..		316.40	
Half-displacement in cubic feet		12977.81	
		2	
Whole displacement in cubic feet		25955.62 ÷ 35 = 741.62 whole displacement in tons.	

	Cubic feet.	Tons.
Displacement found by the vertical sections	25983.88	742.39
Ditto ditto horizontal sections	25955.62	741.62
Mean displacement of the Volage -	25969.75	741.99

The following weights make up the total displacement of this ship. The weight of the hull is calculated by finding the displacement of the ship when launched, in the same manner as the load displacement has been found above.

	Tons.
Weight of hull - - -	371,0
„ ballast - - -	63,0
„ water - - -	53,0
„ tare of casks and tanks -	10,5
„ ship's company, bedding, &c. with provisions for four months, including tare of casks, with the galley, coals, and wood - -	59,0
„ ordnance . - -	32,0
„ powder - - -	3,9
„ shot, round and in boxes -	20,5
„ gunner's stores - -	4,4
„ carpenter's stores -	14,7
„ boatswain's stores, with boats	18,9
„ anchors and cables -	24,6
„ slops, purser's necessaries, marine and officers' stores -	24,5
„ masts, rigging, sails, with spare gear, and spare sails -	42,0
	742,0

The following Table shows the Displacement, in Tons, of Ships of the British Navy, completely armed, stored, and provisioned, for foreign service.

Class of Ship.	Guns. No.	Length on gun-deck.		Breadth extreme.		Draught of water. forward.		Draught of water. abaft.		Depth of keels below lower edge of rabbet.		Displacement in tons.
		ft.	in.	ft.	in.	ft.	in.	ft.	in.	ft.	in.	
Three-decker	120	205	0	54	6	25	1	26	1	2	3	4842
Two-decker	84	196	1½	51	6	22	8	24	8	1	7	3910
,, ,, ...	80	187	5	50	0	22	10	24	2	1	8	3616
,, ,, ...	76	182	0	49	0	21	6	23	0	1	8	3145
,, ,, ...	74	175	6	47	8	21	4	23	6	1	8	2987
Frigate........	60	172	9	43	8	19	6	20	6	1	7	2225
,, ...	50	159	2	41	11	17	6	18	10	1	2	1695
,, ...	46	154	0	39	6	17	6	19	0	1	3	1562
,, ...	28	119	0	33	8	15	8	15	11	1	7	840
,, ...	28	113	10	31	8	14	10	15	10	1	7	742
Corvette	18	113	2	30	6	13	4	14	0	1	4	564
Brig	18	100	0	30	6	11	0	14	9	1	3	458
,, ...	10	90	0	24	6	10	8	12	5	1	6	279
Cutter		67	0	24	6	8	2	12	3	1	1	165
,, ...		57	3	18	9	6	1	10	6	1	1	93
Yacht		103	0	26	6	12	3	13	0	1	2	425

In the design of a ship, reference is first made to the displacement of a ship of the same class; and by making such alterations as the difference of weights in the new ship may require, the value of its displacement will be determined.

There are numerous methods of approximating to the displacement of a ship, which may be occasionally useful, such as by multiplying the area of the midship section, or loadwater section, by certain fractions of the length or breadth; or by multiplying the product of the length, breadth, and depth, by certain co-efficients; the fractions and co-efficients being in all cases dependent on the fulness of the different classes of ships.[1] In the design of a ship, however, nothing should prevent its displacement being calculated in the manner shown in this paper.

Art. II.—*Account of the manner of stowing the Spare Top-mast and other Spare Gear in 10-gun Brigs.* By Captain Pole, R.N.

(*To the Editors of Papers on Naval Architecture.*)

Gentlemen,

The following account of the manner of stowing the spare top-mast and other spare gear of the Falcon, a 10-gun brig, is offered for insertion in your 'Papers on Naval Architecture.'

Figure 4 represents the spare top-mast AB, placed upright on the fore side of the main-mast CD, resting on the keelson at B; Fig. 5 represents a plan of the main-mast partners, EEE represent the wedges of the main-mast, and FFF the wedges which confine the top-mast in its partners.

The other spare spars are stowed as follows: the two top-gallant-masts up and down abaft the fore-mast, and as there is no try-sail-mast, a chock is fitted between and on each side the top-gallant-mast, to take the jaws of the gaff; the spare top-sail-yard is stowed outside above the sills of the ports, and one spare jib-boom and top-gallant-yard on the opposite side; the other spare jib-boom may be stowed across the stern.

The advantages of this method of stowing the spare gear in

[1] Simple methods of approximation of different calculations will be given in a separate article.

small vessels, I consider very great. The top-mast so placed is always ready for going aloft, and by its being lashed to the lower-mast, it becomes a fish and gives support to it, if sprung or wounded; no additional top weight is given by this method, as the centre of gravity of the top-mast thus stowed, is at about the same height as it would be if stowed on the gallows: in larger vessels, the top weight would be reduced, as the depth of the hold being greater in proportion to the length of the mast, so much the more would the top-mast be proportionally housed. By the deck being cleared of the spars, a greater circulation of air would be produced down the hatchways. It gives more room on deck to work the guns, the men can cross the deck before the fore hatchway, in working the ship or in action, without inconvenience, and it enables the cables to be worked with greater ease.

I think if all vessels stowed their spare masts in this manner, it would be found very advantageous, as there is great inconvenience and trouble, attendant with some degree of danger, in casting the boats and booms adrift in bad weather, should it be necessary to get out a top-mast; besides the difficulty of pointing it. In fact, I would go further, I would stow all the rough spars in the same manner, which would clear the decks, and ease the ship, by removing a great weight, which must distress a ship's upper works, so as to bring it on the keelson.

The beams of the 10-gun brigs present no obstacle to this mode of stowing the masts, as the Falcon and Espoir have been fitted in this manner without any difficulty; and I suppose, if thought desirable, the beams of frigates might be so disposed as to admit of it, without any inconvenience.

The only improvement I see necessary, is to have the partners of the top-mast a little further before the lower-mast, which have been so fitted in the Espoir, that the wedges which confine the top-mast, may be independent of those of the main-mast, so that the top-mast may be got aloft without disturbing the wedges of the lower-mast.

I have only further to observe, that I believe it has been generally approved of here; the only objection I have heard, and that only by those who had not seen it, was as to its appearance; but when the top-mast is of the same colour as the

lower-mast, it is scarcely observed, as a proof of which I have been asked by many who came on board, where the top-mast was stowed, so little does it attract the eye.

I remain, Gentlemen, yours &c.,
JOHN POLE.

H. M. Ship Maidstone,
Simon's Bay, June 14, 1829.

ART. III.—*A Treatise concerning the true Method of finding the Proper Area of the Sails for Ships of the Line, and thence the Length of the Masts and Yards; by Fred. H. af Chapman.*

THE following translation of a treatise on the determination of the area of the sails of ships of the line, written by the celebrated naval architect, Admiral Chapman, was first published in a separate pamphlet, and was afterwards published in the old collection of 'Papers on Naval Architecture.' The usefulness of this little treatise, and the great scarcity of copies of it, are the inducements to its republication in this work.

Introduction.—It has been endeavoured time immemorial to find the true proportion of masts for ships: even in this century,[1] celebrated mathematicians have written most elegantly on this subject theoretically, but without any possibility of applying their theory to practice, and consequently without any advantage to the science. The number of masts indeed in large and small vessels has been determined, also their position, and division into top-masts and top-gallant-masts; and, there is now but little variation in the form and relative proportions of the sails; so that we have not only ships of the line, but ships and vessels of all sorts, arrived almost to perfection in their rigging, and having the area of their sails in the best proportion to the size and quality of the vessel: all this has been done by practice and experience alone, sometimes by

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[1] Written at the end of the eighteenth century.

chance, and sometimes by increasing or diminishing the length of the masts and yards till they were of a proper size, without the least assistance of theory.

From all this it would be reasonable to suppose, that those vessels which have such well-proportioned rigging, ought to serve as models for every other vessel of the same size. But as vessels of the same dimensions, nay, even of the same fulness of body in water, may still possess very different qualities, not only in stability, but also in sailing; practice alone has not proved sufficient to determine the alteration of the masts and yards in such a manner, that the momentum of the sails will become equally suited to a ship of other qualities, as it is to the former. It would be still more difficult, if such ships should undergo any alterations in their dimensions, or were to carry lighter or heavier guns, consequently a less or greater number of men to serve the guns, or to carry the guns higher or lower above water, &c. which alterations of course would require alterations in the size of the sails, masts, and yards. These alterations can be known only, either by constantly trying experiments at a great expense, and with much loss of time, or by a well-founded theory. It is the latter which will be here treated of; but only so much of it as applies to the stability of the ship, and not to the distribution fore and aft, which occasions the well-sailing of the ship. This last circumstance depends on such investigations as do not directly belong to this discourse; which, however, does not make any alteration in the area of the sails, but only in the position of the masts, which cannot differ much from what is customary.

It is already said, that the theory here treated of, is only to determine the area of the sails in proportion to the stability of the ship. A ship is at present so rigged, and the sails made in such a manner, that their area can at pleasure be augmented or diminished, according to the force of the wind, or stability of the ship; but that is not the present consideration. It is necessary to determine a certain instance, when certain sails ought to be used, in a determinate strength of wind, and at a time when the well-sailing and stability of a ship of the line are of most consequence, which certainly is, when a ship is in a line of battle, engaging an enemy.

The qualities of a good ship of the line on such an occasion ought therefore to be determined, namely, that she sails and steers well, works well through the wind, and when to windward of the enemy in a top-sail gale, sailing within six points of the wind, carrying three top-sails, three top-gallant-sails, fore-top-mast stay-sail, jib or mizen,[1] all hands at their quarters, the men at the guns, and small-arms to leeward, and every thing properly placed as usual, ready for action, that the ship at this instant possesses such a stability, as not to incline more than about seven degrees.

These are the circumstances from which the whole area of the eight sails is to be determined. What is here to be considered when the area of the sails is to be determined, is the stability of the ship. This depends on two causes: first, on the power of the wind on the sails, and the distance of this power above the centre of gravity of the ship; secondly, on the weight of the men at the guns and small-arms to leeward, and their common centre of gravity from the middle line of the ship.

The momentum of the men from the middle line of the ship, together with the momentum of the stability of the ship, and the number of degrees the ship is allowed to incline, will determine the momentum of the sails; whence we may easily conclude, that nothing can be done in it, without knowing, 1. The whole quantity immersed to the outside of the plank, when the ship is completely armed and fitted for sea; 2. The situation of the centre of gravity of the whole ship, when all the weights are disposed as usual at the time of an engagement with an enemy; and, 3. The distance from the loadwater line to the metacentre.[2]

The first and last circumstances can easily be known, but the second is more difficult. It may be found with a great deal of labour by calculation, very nearly to a certainty; but the best

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[1] That the jib instead of the mizen is used in the calculations, is because the jib is something larger, and has its centre of gravity higher; so that there is more certainty that the momentum of the other sails will not be too great. Chapman.

[2] Chapman measures the stability of a ship in this treatise, as well as in all his other works, by the height of the metacentre above the centre of gravity of the ship: the error of this method has been shown in Article X. of the first volume of this work.

method is to find the centre of gravity [1] by experiments, as related in the *New Transactions of the Swedish Academy of Sciences*, first quarter of the year 1787; which experiments are so necessary to be known in this work, that they are added in a supplement to this small treatise.

In a harbour where a fleet of several ships of the line are lying, such experiments ought to be made, not only when they are completely fitted out or equipped, but when they are unarmed; not only when they are entirely new and quite empty, but also when they are become older, in order to find the centre of gravity of the hull only. The same ought to be done with frigates and smaller armed vessels. All circumstances in these experiments ought to be exactly noted, and preserved as a collection of very useful data. [2]

Such experiments as are here mentioned or recommended, ought to be considered as entirely mechanical; as not designed to find new laws, but only with less trouble and more exactness to find the position of the centre of gravity, in order to avoid a more tedious and long calculation.

It is said in the above-mentioned transactions, that by such experiments the art of ship-building will advance much faster to its perfection than it has ever yet done.

The following treatise is divided into three articles. The first is physical, depending as usual on hypotheses or suppositions, which ought to be admitted as truth when they agree with experimental trials. The second is mathematical, grounded on

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[1] Several methods of determining the situation of the centre of gravity of a ship, have been given by different authors: Chapman gives two methods in his work on ships of the line, one of which is on the same principle as that given by Mr. Abethell in the second volume of 'Papers on Naval Architecture,' page 51; another method is given in the same volume of this work, page 49, by Mr. Barton. Mr. Major has also given a method of finding the centre of gravity of a ship, in the Annals of Philosophy, No. 66, page 411. The necessity of determining the situation of the centre of gravity under different circumstances of all classes of English ships, for the improvement of their design, cannot be too often insisted on.

[2] Some place in the ship should be fixed on, from which the common centre of gravity of all the weights ought to be calculated: for instance, in a ship of the line, the upper edge of the lower-deck beams close to the side, opposite to the main-mast. Chapman.

pure mathematical demonstrations; and the third, shows the application of the whole.

Contents.—Article I. 1. On the effect of the air or wind against an inclined plane.

2. When a ship sails within six points of the wind, to find the obliquity of the sail with the direction of the wind, so that the effect which forces the ship forward may be a maximum.

3. To find the relative force of the wind, which occasions the ship to heel, or incline sideways.

4. The absolute force of the wind when it blows more or less.

5. The force of the wind on the sails, when they are braced within three points of the wind's true direction.

Art. II. 6. To find the value of the momentum of the power of the sails, which causes the ship to incline a fixed number of degrees.

7. To find the area of the main-top-sail and main-top-gallant-sail.

8. To find their common centre of gravity.

9. Rules necessary to be known before the proportion of the sails belonging to the other masts can be determined.

10. To find the area of the sails belonging to the fore and mizen masts, and the height of the common centre of gravity of the sails belonging to the three masts, above the lower edge of the main-top-sail.

11. To find the momentum of all the eight sails from the centre of gravity of the ship, and also the momentum of the power of the sails.

Art. III. 12. To find the momentum of the stability of a ship of 74 guns, and also the momentum of the men quartered to leeward at the guns and small-arms.

13. To find the power of the sails, and thence the breadth of the lower edge of the main-top-sail.

14. To find thence the proportion of all the sails.

15. To find the length of the masts and yards.

16. A table constructed from the calculation of the area of the sails.

17. To find how much the ship will incline only by the weight of the men at the guns and small-arms to leeward; and how

much she will incline by the force of the wind on the sails only, without the men being to leeward.

18. When a ship is beating off a lee-shore, with a press of sail in a stiff gale of wind, to calculate how much she will incline, as a proof that the area of the sails is well-proportioned to the stability of the ship.

19. To determine the area of the sails for another ship of the line of an equal size and dimensions, but of less stability.

20. When there is a properly and well-rigged ship of the line, the area of whose sails bears the best proportion to her stability, how to find a rule by which the area of sails for all other ships of the line may acquire the same proportion to their stability.

Treatise.—Art. I. 1. When a quantity of air strikes or impinges upon a plane AB, Fig. 6, inclined to DC, the direction of the wind or air, every particle of air does not strike directly on the plane, but the whole quantity of air bends itself and slides along the plane, and by its pressure, has nearly the same effect as if it immediately struck the plane in the direction DC: so that when the velocity of the wind increases, the pressure on the inclined plane is also increased. Let, therefore, DC denote the absolute force and direction of the wind, which as usual must be resolved into two others, DE perpendicular to BA, and EC parallel to the plane; whence DE is that power which presses perpendicularly against the plane. Draw EF perpendicular to DC, then FE is the lateral force which acts perpendicularly to the direction of the wind DC, which ought to be multiplied into the whole area of the plane, and not into its projection.

2. To find by projection the power of the wind on the sails in different positions, as well that which makes the ship incline as that which forces her forward, and to determine in which position of the sails this last will be a maximum, it is here supposed, that the ship sails within six points of the wind; and no one ought to presume a ship of the line can lie nearer in a heavy sea.

Draw the line BA, Fig. 7, which represents the force and direction of the wind from B to A; and describe on it a semicircle divided into eight equal parts, 1, 2, 3, 4, 5, 6, 7, and 8. From A, through the sixth division, draw the line A6C, then AC becomes the middle line or axis of the ship, which makes

an angle of six points, or 67° 30′ with the direction of the wind.

From A draw the lines A1, A2, A3, A4, and A5, which lines are supposed to be the different positions of the sails. Draw B1, B2, B3, B4, and B5; then these lines show the angle of incidence which the wind makes with the sails; and as these lines B1, B2, &c. are perpendicular to A1, A2, &c. they also express that part of the wind's power which acts on the sails. It is this power alone, which not only forces the ship forward, but also makes her incline.

Draw, therefore, the line B6, which is the sine of the angle BAC, or the angle which the direction of the wind makes with the middle line of the ship; draw all the lines 1D, 2E, 3F, 4G, and 5H, parallel to AC the middle line of the ship; then each of these lines represents the middle line.

Now as B1, B2, &c. express the power which moves the ship forward, and also occasions it to incline, D1, E2, F3, G4, and H5, express the power which moves the ship forward, and BD, BE, &c. the power which occasions the ship to incline, or move about its axis or middle line AC. But of all the powers, D1, E2, F3, G4, and H5, which move the ship forward, FE is the greatest, which happens to be in that place where the sail A3 cuts the angle BAC into two equal parts; which position of the sail, as most advantageous for forcing the ship forward, will here be admitted.

3. Produce 3F, which will meet AB in the centre of the circle; then BF=half B6, is that power which in this case makes the ship incline, or turns it about the middle line or axis, = half the sine of the angle BAC; consequently, if the absolute power of the wind BA = 1, then B6, the sine of the angle BAC = 0,9239, and the half of B6, or BF = 0,4619 = t.[1]

[1] In this construction, the angle of the direction of the sail with the middle line of the ship is 33° 45′, which is much greater than the angle which the most correct theories on sails determine to be the best for a ship sailing close to the wind; and greater than the angle at which the sails are set by practice under these circumstances, by the most experienced sailors. When a ship's course is six points from the wind, Euler gives the angle of the direction of the wind with the sail 26°, and the angle of the direction of the sail with the middle line of the ship 21°. By calculating from these angles, the inclining force of the wind is found to be 0,4092, instead of 0,4619, as given by Chapman. This subject requires to be considered in connexion with the angle of leeway, which appears to be neglected in this construction.

This method of determining the power of the wind on the sails, when sailing by the wind, is not exactly true, because the sails are hollow or bent, and not plane surfaces, as is here supposed; but as this, together with what is treated of in section 1, agrees very well with practice (from calculations made on ships of different stabilities), it gives a very good proportion for the area of the sails in comparison with the stability of the ship, when the principle here used is followed in its whole extent.

4. It being necessary to know the absolute force of the wind, blowing more or less, when the proportion of the areas of the sails is to be determined, the following experiments were made.

In the year 1779, a trial was made with a new 60-gun ship, when such an anemometer was used as is described by M. Bouguer, in his *Traité du Navire*, of one foot square. With this instrument, the force of the wind was measured at different times; and after several consultations with all the officers on board, on the characters which ought to be given to the different winds and gales which blew during the expedition, the following were agreed on, viz.:

When the force of the wind was

lb.		lb.
1	it was called a top-gallant-sail wind . .	$1,14 = v$
$1\frac{1}{2}$	. . . . . . brisk top-gallant-sail wind	$1,71 = v$
2	. . . . . . top-sail wind	$2,29 = v$
$2\frac{1}{2}$	. . . . . . brisk top-sail wind . . .	$2,86 = v$
3	. . . . . . reefed top-sail wind . .	$3,43 = v$
4	. . . . . . close-reefed top-sail wind	$4,57 = v$
5	. . . . . . courses or lower-sail wind	$5,71 = v$
7 to 8	. . . . . . half a storm	$8 \text{ to } 9 = v$
10 to 11	. . . . . . full storm	— —

It was not from the behaviour of this ship that the force of the wind received these characters,—because she was very stiff, and could carry her top-gallant-sails very well when others were obliged to reef their top-sails; but the officers on board, who were all old, experienced seamen, did, with their common deliberate consent, determine the characters above-mentioned.

Now, as the wind acts also on the ship's hull and rigging, some addition ought to be made to the wind's power on the

sails, which addition has been taken in the calculations to be one-seventh part of the whole power. This is the reason for the addition to the above-mentioned characters of the wind's power, and for this greater or increased power being stated $= v$.

5. Now, as the power of the wind on a plane whose area is one foot square is $= v$ lb., and a cubic foot of salt water is in weight $= 63$ lb., the power of the wind is on an area of a foot square $= \frac{v}{63}$ cubic feet of water; and this multiplied by t or

$$0,4619, (\S\ 3) = \frac{t.v}{63} = \frac{0,4619.v}{63} = \text{the power of the wind on a}$$

sail of one foot square, when it makes an angle of three points with the wind's true direction; and when this power is multiplied into the area of the sail, (§ 1) it gives what is here called the power of the sails.

Art. II. 6. To find the value of the momentum of the power of the sails, to give a ship of the line a determined inclination or heeling.

Suppose A, Fig. 8, to be the centre of gravity of the ship, b the metacentre, c the centre of gravity of the weight of a certain number of men at any height above the centre of gravity, (see the Supplement, page 59,) and d the centre of gravity of the sails when the ship is upright.

From c and d draw lines horizontally, or perpendicularly to Ad. Let the men at c be removed a given distance cf, and at the same time let the force of the wind act on the sails at d, always perpendicular to the mast, or middle line Ad of the ship.

By the removal of the men, and the force of the wind on the sails, the ship is caused to revolve round an axis passing through its centre of gravity A, and takes an inclination, so that b comes to B, c to C, d to D, and f to F. Through B, which is now the metacentre, draw a vertical line BI, then the water acts with a force that is equal to the whole weight of the ship in the direction IB, to oppose the inclination of the ship.

Suppose the ship is to receive a determined inclination AD; from C draw CG horizontally, and from F draw the line FG at right angles to it, or vertically, and from A draw AI perpendicular to BI or Ad. Put $AB = a$, $CF = b$, $AD = z$, $AI = x$,

and $CG = y$. Let the whole weight of the ship, or its displacement $= Q$, the weight of the men $= P$, and the power of the sails $= S$; then it is evident that the ship retains the same inclination, or is at rest, when $yP + zS = xQ$.

Let the angle ABI, the inclination of the ship $= s$, then $x = \frac{sin.\ s.\ a}{rad.}$, and $y = \frac{cos.\ s.\ b}{rad.}$; whence $xQ = \frac{sin.\ s.\ aQ}{rad.}$, and $yP = \frac{cos.\ s.\ bP}{rad.}$. Put the momentum of the power of the sails $zS = M$, then $M = \frac{sin.\ s.\ aQ}{rad.} - \frac{cos.\ s.\ bP}{rad.}$, which is a general expression for all ships, for the power which causes them to incline; and as the quantities in this expression are known, it will not be difficult to find the absolute momentum of the power of the sails, M. It is this that was proposed to be found; the manner of obtaining from this momentum, the areas of the sails themselves will be seen in the following sections.

7. Before the areas of the main-top-sail and main-top-gallant-sail can be found, it is necessary to know their figures. Let their usual figures be assumed, and let the breadth of the lower edge of the main-top-sail be the standard by which all proportions concerning the sails are formed.

Put the breadth of the main-top-sail below, Fig. 9	$IK = x$
Its breadth above.	$LM = mx = 0{,}75\ x$
Its depth	$DF = nx = 0{,}72\ x$
Breadth of top-gallant-sail above .	$NO = px = 0{,}54\ x$
Its depth	$PH = qx = 0{,}44\ x$
The distance between these two sails to give room for the top-sail-yard and sheet block	$FH = rnx,\ r = 0.0322$
From the lower edge of the main-top-sail, to the upper edge of the main trestle-trees	$DE = fnx,\ f = 0.18$
From the upper edge of main-top-sail to the upper end of main-top-mast	$FG = hnx,\ h = 0.23$

Head of the main-mast above the trestle-trees . . . . $= EQ = FG = hnx$

The breadth of the lower edge of the main-top-sail being represented by x, the area of the main-top-sail $= \frac{1+m}{2}.\ n\ x^2$, and of the top-gallant-sail $= \frac{m+p}{2}.\ q\,x^2$; whence the area of both sails together is $= x^2.\ \frac{n.\ \overline{1+m}+q.\ \overline{m+p}}{2}$; put this $= cx^2$; then substituting the known quantities, $cx^2 = 0{,}9138x^2 =$ the area of the main-top-sail and main-top-gallant-sail together.

8. The expression for the area of both sails for the main-mast being known, their common centre of gravity must also be found. The height of the centre of gravity of the main-top-sail from its lower edge $= x\,n.\ \frac{2\,m+1}{3.m+1}$, and the height of the centre of gravity of the main-top-gallant-sail from its lower edge $= x.\ q.\ \frac{2\,p+m}{3.p+m}$; the distance between the main-top-sail and top-gallant-sail $= rnx$, (§ 7) and $nx+rnx = x.\ n.\ \overline{1+r}$ is equal to the distance from the lower edge of the main-top-sail to the lower edge of the top-gallant-sail; and

$$x.\,n.\,\overline{1+r}+q.\frac{2\,p+m}{3\,p+m} = x.\,n.\frac{3.\ \overline{1+r}\ \ \overline{p+m}+q.\ 2\,\overline{p+m}}{3.\,p+m} =$$

to the height of the centre of gravity of the top-gallant-sail above the lower edge of the top-sail; whence

$$x.\,n.\frac{\frac{2\,m+1}{3.m+1}.\ \frac{1+m}{2}}{\frac{1+m.}{2}n+q.\frac{m+p}{2}} \cdot \frac{n+\frac{n.\overline{1+r}.3.\overline{p+m}+q.2\overline{p+m}}{3.p+m}.q.\frac{m+p}{2}}{\frac{1+m}{2}.\,n+q.\frac{m+p}{2}}$$

$$= x.\,n^2.\frac{\overline{2\,m+1}+q.\ 3.\ n.\ \overline{1+r}.\overline{p+m}+q.\ 2\overline{p+m}}{3.\,n.\ \overline{1+m}+q.\overline{m+p}} = g\,x;$$

and when the known quantities are substituted, $gx = 0{,}5318.x$, which is the height of the common centre of gravity of both the sails above the lower edge of the main-top-sail.

9. It is necessary, before the area of the sails for the other masts, and situation of their centre of gravity, can be known, to introduce the following particulars, which also very nearly agree with common practice. The head of the fore-mast below the head of the main-mast $= \frac{2}{5}$ the head of the main-mast. All dimensions belonging to the sails of the fore-mast = 0,9 those belonging to the main-mast; and those belonging to the mizen-mast = 0,72 those of the main-mast. The head of the mizen-mast above the upper edge of the main trestle-trees = 0,091 the length of the head of the main-mast. The lower edge of the mizen top-sail below the upper edge of its trestle-trees = 0,688 the length of the head of the mizen-mast. From which we have,

The distance from upper edge of main-top-sail to the head of the top-mast -	$= FG = hn = 0{,}23.0{,}72.x = 0{,}1656\,x$
Length of the head of the main-mast above the upper edge of the trestle-trees - -	$EQ = hn = 0{,}23.0{,}72.x = 0{,}1656\,x$
From the trestle-trees to the lower edge of main-top-sail -	$= DE = fn = 0{,}18.\,0{,}72\,x = 0{,}1296\,x$
Head of fore-mast below the head of the main-mast - - -	$= \frac{2}{5}\,hn = \frac{2}{5}.\,0{,}23.\,0{,}72\,x = 0{,}0662\,x$
Length of fore-mast head - - - -	$= 0{,}9\,hn = 0{,}9.\,0{,}23.\,0{,}72\,x = 0{,}149\,x$
From the upper side of fore trestle-trees to the lower edge of the fore-top-sail -	$= 0{,}9\,fn = 0{,}9.\,0{,}18.\,0{,}72\,x = 0{,}1166\,x$
Length of the head of the mizen-mast -	$= 0{,}72\,hn = 0{,}72.0{,}23.0{,}72\,x = 0{,}1192\,x$

From the main-mast trestle-trees to the lower edge of the mizen-top-sail - $= 0,688.0,72hn = 0,688.0,72.0,23.0,72x = 0,082x$

The head of the mizen-mast above the main-mast trestle-trees $= 0,091\,hn = 0.091.0,23.0,72\,x = 0,0151\,x$

Lower edge of the main-top-sail below the head of the mizen-mast - - $= 0,1656\,x + 0,1296\,x = 0,2952\,x$

Lower edge of the fore-top-sail below the head of the main-mast - - - - $= 0,0662\,x + 0,149\,x + 0,1166\,x - 0,2952\,x = 0,0366\,x =$ the distance the lower edge of the fore-top-sail is below the lower edge of the main-top-sail.

Lower edge of mizen-top-sail below the head of the mizen-mast - - - - - $= 0,1192\,x + 0,082\,x = 0,2012\,x$

Head of mizen-mast above the main trestle-trees - - - - - - - - - - - - $= 0,0151\,x$

$0,1861\,x$

From the main trestle-trees to the lower edge of main-top-sail - - - - - - - - - - $= 0,1296\,x$

$0,0565\,x$

= distance of the lower edge of the mizen-top-sail below the lower edge of the main-top-sail.

To help the imagination, let fig. 10 represent a usual rigging draught of a ship of war, whose eight sails, before mentioned, (see the introduction,) are shown on it. The centre

of gravity is supposed to be in the line AA, B the upper deck; and when the lower end of the main-top-mast reaches the line CC, its head is even with the upper edge of the main trestle-trees; the lower edge of the top-sail is at D, and the common centre of the fore-top-mast stay-sail and jib, at T.

10. It will not now be difficult to find the area and centre of gravity of the sails belonging to the other two masts, because $\overline{0,9}^2 . cx^2 =$ the area of both sails belonging to the foremast $=$ $0,81 . 0,9138 . x^2 = 0,74018 . x^2$; and $\overline{0,72}^2 . cx^2 =$ the area of both the sails belonging to all the mizen-mast $=$ $0,5184 . 0,9138 . x^2 = 0,4737 x^2$; whence the area of the sails belonging to all the three masts is $= 2,1277 x^2$.

The common centre of gravity of the fore-top-sail and fore-top-gallant-sail, from the lower edge of the fore-top-sail $=$ $0,9 . gx$, and the common centre of gravity of the mizen-top-sail and top-gallant-sail from the lower edge of the mizen-top-sail $= 0,72 gx$.

From this, and what has been shown at the end of § 9, we have $\overline{0,9 . g - 0,0366} . x =$ the height of the centre of gravity of both sails belonging to the fore-mast above the lower edge of the main-top-sail; and $\overline{0,72 . g - 0,0565} . x =$ the height of the centre of gravity of both sails belonging to the mizen-mast above the lower edge of the main-top-sail; from which

$$x . \frac{g . c + \overline{0,9 . g - 0,0366} . \overline{0,9}^2 . c + \overline{0,72 . g - 0,0565}}{c + \overline{0,9}^2 . c + \overline{0,72}^2 . c} .$$

$$\frac{\overline{0,72}^2 . c}{c + \overline{0,9}^2 . c + \overline{0,72}^2 . c} = x . \frac{g . + \overline{0,9 . g - 0,0366} . \overline{0,9}^2}{1 + \overline{0,9}^2 + \overline{0,72}^2} +$$

$$\frac{\overline{0,72 . g - 0,0565} . \overline{0.72}^2}{1 + \overline{0,9}^2 + \overline{0,72}^2} = 0,4548 x,$$

which is the height of the common centre of gravity of all the sails belonging to the three masts, above the lower edge of the main-top-sail, since the value of all the known quantities have been inserted.

11. Thus nothing remains in order to obtain the momentum of all the sails belonging to the three masts, but to determine the distance from the centre of gravity of the ship to the lower

edge of the main-top-sail; this distance, however, cannot be taken at pleasure. If too great, then the top-sail will become too small; and if too small, then the top-sail will become too long in proportion to the mast; consequently it will be necessary to find a top-sail of such a depth, that the top-mast, which is to carry the sail, may acquire a proportionable length in comparison with the height of the mast above deck, so that it may be conveniently put into its place and raised.

Let, therefore, A, fig. 9, be the centre of gravity of the ship, B the upper edge of the upper deck amidships, C the lower end of the top-mast, which has a given distance, BC, above the deck when lowered; and the length of the top-mast equal to the distance from C to the upper edge of the main trestle-trees E; whence the length of the top-mast will be = CE, and = EG, when aloft. Then the distance from C, the lower end of the main-top-mast, when struck, to the lower edge of the main-top-sail D, is $= CD = DF + FG - 2\,DE = nx + hnx - 2\,fnx = 0{,}72.x + 0{,}23.0{,}72.x - 2.\,0{,}18.0{,}72.x = 0{,}6264.x = CD$.

Consequently the distance from C to the common centre of gravity of all the sails belonging to the three masts is $= 0{,}6264\,x + 0{,}4548.x$; and if the distance from the centre of gravity A to C be put $= d$, the momentum of all the sails from the centre of gravity of the ship will be $= \overline{d + 0{,}6264.x + 0{,}4548.x}.\,2{,}1277.x^2$. But this is not the whole momentum of the sails; there still remain the two sails belonging to the bowsprit.

As the area of these two sails, as well as the height of the centre of gravity above that of the ship, depend very much on the elevation and length of the bowsprit, these circumstances ought first to be determined. As to its situation, it is not liable to any change; and when its elevation is about 25 degrees, it seems to be raised sufficiently out of the water in a heavy sea when the ship pitches; and as to its length, or rather the place where these two sails ought to be fixed to the bowsprit, the following supposition will answer our purpose very well: let the whole length of the ship between the perpendiculars of the stem and stern-post $= l$, and the distance from the centre of gravity of the ship to the upper side of the main

trestle-trees $= h$, then the distance from the perpendicular of the stem along the bowsprit to the tack of the fore-top-mast stay-sail may be put $= \frac{\overline{lh}}{2,558}$, and the distance from the same perpendicular to the jib $= \frac{\overline{lh}^{\frac{1}{2}}}{1,47}$. And the area of both sails together, will agree very well with practice, when it is taken as one-sixth part of the six sails belonging to the three masts; and the area of the jib is to the area of the fore-top-mast stay-sail as 4 to 3. Their common centre of gravity T, fig. 10, above C, will be very nearly the distance $\frac{CD}{1,118} = 0,56\,x$; and as the sum of both these sails together is $\frac{2,1277}{6} \cdot x^2 = 0,3546\,x^2$, their momentum from the centre of gravity of the ship will be $= \overline{d + 0,56\;x} . 0,3546\,x^2$; whence the momentum of all the eight sails, from the centre of gravity A of the ship, will be

$= \overline{d + 0,6264 . x + 0,4548 . x} . 2,1277 . x^2 + \overline{d + 0,56 x} . 0,3546\,x^2$

$= \overline{d + 1,0812\,x} . 2,1277\,x^2 + \overline{d + 0,56\;x} . 0,3546 z^2$, which is

$= \overline{d . 2,1277\,x^2 + 2,3 . x^3} + \overline{d . 0,3546\,x^2 + 0,1986\,x^3}$ [1]

$= d . 2,4823\,x^2 + 2,4986\,x^3$. When this is multiplied into the power of the wind $\frac{0,4619 . v}{63}$ (§ 5,) or if the momentum of the power of the wind M, (§ 6), be divided by this power of the wind, we have $d . 2,4823 . x^2 + 2,4986\,x^3 = \frac{63\text{ M}}{0,4619 . v}$; and this is a general expression for the momentum of the sails for all ships of the line in stronger or weaker winds.

Art. III. 12. To apply this in practice, suppose the area of

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[1] These expressions are placed separately, the first being the momentum of all the sails belonging to the three masts, and the second of those belonging to the bowsprit, in order that if, at any time, it should be found necessary to alter the latter, it may be easily done. Chapman.

the sails, and the length of the masts and yards, for a ship of 74 guns, are to be found, whose

		Feet.
Length between the perpendiculars at the stem and stern-post	- - - -	= 184
Breadth moulded	- - - -	= $49\frac{2}{3}$
Draught of water abaft	- - -	= 22
Ditto forward	- - - -	= $20\frac{1}{2}$
Height of ports above the water in midships		= $6\frac{5}{6}$

Its defence, on the lower deck, is 28 guns, 36-pounders; on the upper deck 30 24-pounders; and on the quarter-deck and forecastle 16 12-pounders. Its displacement, to the outside of the planks, when armed, = Q = 100500 cubic feet. The centre of gravity of the whole ship above the water, when completely armed, and every thing placed as usual in an engagement, and all hands to their quarters = 2,1 feet. The distance between this centre and the metacentre, = 4,22 feet = a. The number of men to a 36-pounder = 12, to a 24-pounder 9, and to a 12-pounder 7. The whole number of men at the guns, to leeward = 359, and to the small-arms on the gangway and poop = 50; in all 409. If the weight of one man is = 2,7 cubic feet of salt water, then the weight of all these men is = 2,7 . 409 = 1104 cubic feet = P. Suppose their common centre of gravity, from the middle line of the ship, is = 15 feet = b, then the momentum of these men, from the middle line of the ship, is = 1104 . 15 = 16560 = bP.

The momentum of the stability of the ship is = 100500 . 4,22 = 424100 = aQ. From the centre of gravity of the ship to the upper edge of the upper deck at the main-mast = AB = = 10,5, fig. 10.

When the upper end of the top-mast is even with the upper edge of the trestle-trees, the lower edge of the fid is to be, from the upper deck, a distance BC = 5,7 feet[1]; whence the dis-

[1] The distance BC = 57, feet is for this purpose; that when the top-mast is to be raised, and its lower end stands on deck, the upper end may pass the eye or collar of the stay, to come to its place. This distance ought to be more or less, according to the size of the ship; but for three-decked ships, the length of the main-top-mast, from the lower edge of the fid to the top-end, is to be equal to the distance between the upper deck and the upper edge of the trestle-trees. Chapman.

tance from the centre of gravity of the ship to the fid of the top-mast is AC $= 10{,}5 + 5{,}7 = 16{,}2$ feet $= d$.

13. To find thence the momentum of the power of the sails, M, which is $= \frac{sin.\ s.\ a\,Q}{rad.} - \frac{cos.\ s.\ b\,P}{rad.}$, (§ 6,) the inclination of the ship being assumed to be 7 degrees.

$$s = 7°,\ a\,Q = 424110, \text{ and } b\,P = 16560.$$

$$\begin{array}{lcl}
\text{Log. } sin.\ 7° & = & 9{,}0858945 \\
\text{Log. } 424110 & = & 5{,}6274683 \\
\hline
 & & 14{,}7133628 \\
\text{Log. } rad. & = & 10{,}0000000 \\
\hline
 & & 4{,}7133628 = 51685 \\
\text{Log. } cos.\ 7° & = & 9{,}9967507 \\
\text{Log. } 16560 & = & 4{,}2190603 \\
\hline
 & & 14{,}2158110 \\
\text{Log. } rad. & = & 10{,}0000000 \\
\hline
 & & 4{,}2158110 = 16437 \\
\end{array}$$

Momentum of the force of the sails M $= 35248$

It was also a condition, that when the ship should incline 7 degrees, it was to be in a top-sail gale, then $v = 2{,}29\,lb.$ (§ 4);

whence $\frac{63}{0{,}4619.\,v}$, (§ 11) $= \frac{63}{0{,}4619.\ 2{,}29} = 59{,}56$; and as $d = 16{,}2$, (§ 12,) the general expression (§ 11) will become $16{,}2.\ 2{,}4823\,x^2 + 2{,}4986\,x^3 = 59{,}56.\ 35248$, or $40{,}213\,x^2 + 2{,}4986\,x^3 = 2099371$.

The greatest difficulty now is to find the value of x. See Simpson's Algebra, page 149. Suppose an equation $mx^2 + nx^3 = W$; from the nature of the equation, by a few trials, we may obtain very nearly the true value of x, which put $= r$, and let $r + z = x$, then $z = \frac{W - nr^3 - mr^2}{3\ nr^2 + 2\ mr}$; when this value

of z is added to that of r, we have the value of x sufficiently exact.

As it is found, by trial, that 90 is near the true value of x, let $r = 90$, and as $n = 2,4986$, $m = 40,213$, and $W = 2099371$,

$$\text{then } z = \frac{2099371 - 2,4986.\overline{90}^3 - 40,213.\overline{90}^2}{3.2,4986.\overline{90}^2 + 2.40,213.90} = -0,71,$$

which, when added to 90, is $90 - 0,71 = 89,29 = x =$ to the breadth of the lower edge of the main-top-sail; hence all the sails, masts, and yards, are to take their proportions. The breadth, below and above, and the depth, of the sails, will be first found.

14. Breadth of the main-top-sail below $IK = x$ - - $= 89,29$
Breadth above (§ 7) $LM = mx$ $0,75.89,29 = 66,967$
Depth - - $DF = nx = 0,72.89,29 = 64,289$
Main-top-gallant-sail, breadth below $LM = mx$ - - $= 66,967$
Breadth above - $NO = px = 0,54.89,29 = 48,217$
Depth - $PH = qx = 0,44.89,29 = 39,288$

The dimensions of the sails belonging to the fore-mast = 0,9 those of the main-mast; whence

Breadth of the fore-top-sail below $= 0,9.89,29 = 80,361$
Breadth above - - $= 0,9.66,967 = 60,27$
Depth - - - $= 0,9.64,289 = 57,86$
Top-gallant-sail, breadth below - $= 60,27$
Breadth above - $= 0,9.48,217 = 43,395$
Depth - - - $= 0,9.39,288 = 35,359$

The dimensions of the sails belonging to the mizen-mast are = 0,72 those of the main-mast; whence

Breadth of the mizen top-sail below - - $= 0,72.89,29 = 64,289$
Breadth above - - $= 0,72.66,967 = 48,216$
Depth - - $= 0,72.64,289 = 46,288$
Top-gallant, breadth below - - $= 48,216$
Breadth above - $= 0,72.48,217 = 34,716$
Depth - - - $= 0,72.39,288 = 28,287$

The breadth of the sails, added to the usual length of the yard-arms, gives the length of the yards.

15. It now remains to find the Length of the lower-masts and top-masts, from the breadth below of the main-top-sail.

To find the Length of the Main-Mast.

From the upper water-line to the ship's centre of gravity A, (§ 12,) fig. 9 - -	=	2,1
From the centre of gravity A to the top-mast fid - = AC - -	=	16,2
From C to the lower edge of the top-sail D - = CD = 0,6264. 89,29, (§ 11,)	=	55,93
From D to E, or upper edge of the trestle-trees = DE = 0,1296. 89,29, (§ 9,)	=	11,57
Length of the head above the trestle-trees - - = EQ = 0,1656. 89,29, (§ 9)	=	14,79
The length of the mast above the water-line	=	100,59
From the water-line to the keelson -	=	15,75
The whole length of the main-mast - -	=	116,34

The length of the main-top-mast from the lower edge of the fid = CD + DE = 55,93 + 11,57 = 67,5

Length of the top-gallant-mast from the fid to the upper part of the hounds = FH (§ 7) + HP — $\frac{1}{2}$ FG + 4,5 (4,5 being the distance from the top-gallant-sail to the upper part of the hounds) which is = 2,07 + 39,288 — 7,39 + 4,5 = 38,468

Head of the fore-mast below the head of the main-mast - = $\frac{2}{5}$. 14,79 = 5,91

Length of the head of the fore-mast - - - = 0,9. 14,79 = 13,31

Length of the fore-top-mast - = 0,9. 67,5 = 60,75

Length of the top-gallant-mast to the rigging - - $= 0{,}9 . 38{,}468 = 34{,}62$

Mizen-mast-head, below the head of the main-mast $= 14{,}79 - 1{,}39$ (§ 9) $= 13{,}4$

Length of the head of the mizen-mast - - $= 0{,}72 . 14{,}79 = 10{,}65$

If the lower edge of the mizen-top-sail should be, in proportion, as much below the trestle-trees as the other top-sails below theirs, it should be - - - - $= 8{,}33$

But this distance is to be $= 0{,}688 . 10{,}65$ (§ 9) $= 7{,}33$

And, consequently, comes higher than in that proportion - - - - - $= 1{,}0$

Whence the length of the mizen-top-mast will be $= 0{,}72 . 67{,}5 = 48{,}6 + 1{,}0 = 49{,}6$

Length of the top-gallant-mast to the rigging $= 0{,}72 . 38{,}47$ - $= 27{,}7$

From the water-line to the head of the fore-mast - - $= 100{,}59 - 5{,}91$ - $= 94{,}68$

From the water-line to the head of the mizen-mast - - - $= 100{,}59 - 13{,}4$ - $= 87{,}19$

When to this is added the distance from the water-line to the keelson, we have the whole length of those masts.

When the places for the tacks of the fore-top-mast stay-sail and the jib are known, the length of the bowsprit and jib-boom will be easily determined, when such lengths are added thereto as are found necessary for the sake of rigging.

From the perpendicular of the stem along the bowsprit to the tack of the fore-top-mast stay-sail $= \frac{\overline{lh}^{\frac{1}{2}}}{2{,}558}$ (§ 11) $=$ $\frac{\overline{184.83{,}7}^{\frac{1}{2}}}{2{,}558} = \frac{124{,}1}{2{,}588} = 48{,}53$; and to the tack of the jib $=$ $\frac{\overline{lh}^{\frac{1}{2}}}{1{,}47} = \frac{124{,}1}{1{,}47} = 84{,}42.$

Perhaps something ought to be mentioned concerning the heads of top-gallant-masts; they may, however, be made at discretion. If top-gallant royals are to be used, the royal-masts must be in proportion to the depth of the sails. The length of each of the top-sail yard-arms ought not to be less than $\frac{1}{8}$ part of the breadth of the head of the sail, for the sake of the last reef. And when the length of the yard-arms of the lower yards is $\frac{1}{10}$ part of the breadth of the top-sail at the foot rope, the total length of the top-sail-yard is in proportion to the total length of the yard, as 35 to 44. The length of each of the top-gallant yard-arms, is $\frac{1}{10}$ part of the breadth of the sail at the head-rope.

As to the length of the mizen and sprit-sail-yards, every one knows what proportion to give them. Thus, I presume, every thing is here said that is necessary to be known in finding the length of the masts and yards for ships of the line; which it was the object of this treatise to determine.

16. To be convinced of the justness of these calculations, make a rigging draught, as Fig. 10, of the size necessary, with all the sails and their centres of gravity; and construct the following table, either from this draught, or directly from the calculations themselves; then it will be found, that the area of the sails and their momentum agree exactly with the rules given, and the momentum of the power of the sails is as it ought to be when the ship, in a top-sail gale, is allowed to incline 7 degrees.[1]

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[1] In these calculations the value of x, with all its decimals, has been used only to show the exactness of the method; but this nicety is not necessary in practice. The decimals, when less than a half, may be omitted. Chapman.

	Breadth of the lower edge of the sails.	Breadth of the upper edge of the sails.	Mean of these breadths.	Depth of the sails.	Area of the sails.	From the lower edge of the sails to the centre of gravity.	From the centre of gravity of the ship to the centre of gravity of the sails.	Momentum of the sails from the centre of gravity of the ship.
	Feet.	Feet.	Feet.	Feet.	Square Feet.	Feet.	Feet.	
Mizen top-sail	64,289	48,216	56,252	46,288	2603,79	22,04	89,12	232049,76
Mizen top-gallant-sail	48,216	34,716	41,466	28,287	1172,95	11,20	128,23	150407,38
Main top-sail	89,290	66,967	78,128	64,289	5022,77	30,61	102,74	516039,39
Main top-gallant-sail	66,967	48,217	57,592	39,288	2262,67	15,56	157,04	355329,70
Fore top-sail	80,361	60,270	70,315	57,860	4068,42	27,55	96,41	392236,37
Fore top-gallant-sail	60,270	43,395	51,832	35,359	1832,72	14,00	145,27	266239,23
Fore top-mast stay-sail					1211,66	}	66,16	187048,87
Flying jib					1615,56			

Sum of the area of the sails .... = 19790,54

The area of the sails ought to be $= 2,4823.\overline{89,29}^2$ (§ 11) .... = 19790,63

Sum of the momentum of the sails .... = 2099350,70

Which, multiplied by $\frac{1}{59,56}$, gives the momentum of the power of the sails .... = 35247,66

Momentum of the power of the sails in proportion to the stability of the ship, M (§ 13) .... = 35248,00

17. It has been constantly supposed in the calculations, that when the ship is sailing on a wind, the men at the small-arms have been to leeward; but it will be useful to know how much the ship will incline by each of these powers separately.

It will be easily known how much the ship inclines by the men only, if we refer to § 6, where it is found, that $M = \frac{sin.\ s.\ a\ Q}{rad.} - \frac{cos.\ s.\ b\ P}{rad.}$; but as the force of the wind is not in question, M becomes $= o$, and we then have $sin.\ s.\ a\ Q = cos.\ s.\ b\ P$; so that $\frac{a\ Q}{b\ P} = \frac{cos.\ s}{sin.\ s}$, or $log.\ a\ Q - log.\ b\ P = log.\ cos.\ s - log.\ sin.\ s$, whence the sine of the angle $s = 2^\circ\ 14'$; which is the inclination caused by the men to leeward only; and when this is subtracted from 7°, the whole inclination, there remains $4^\circ\ 46'$ for the inclination of the ship by the sails only. All circumstances concerning the wind and sails, are supposed the same as they have been admitted from the beginning of this treatise.

18. It is observed in the introduction, that it is necessary to determine a certain instance, when certain sails ought to be used, in a determinate strength of wind, and at a time when the well-sailing and stability of a ship of the line are of most consequence, as a foundation to make the area of the sails and its momentum in proportion to the stability of the ship and that this ought to be at a time when the ship is in action with an enemy in a line of battle, &c.

But adopt another circumstance, and it will be found that this theory will nevertheless be equally applicable. For instance, suppose this ship is obliged with its sails to work off a lee-shore, in a close-reefed top-sail gale, with two reefs in the main and fore top-sails, and one in the mizen top-sail,[1] the main and fore-sail, mizen, the main and mizen stay-sails, the main and fore top-mast stay-sails, and the jib on the jib-boom; suppose the power of the wind to be = 4 lb. (§ 4), then

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[1] The main and fore top-sails are supposed to have four reefs, of which the second takes up $\frac{1}{4}$ of the depth, and the mizen top-sail only two reefs. Chapman.

we have $v = 4{,}57$ lb., which is to be used in the expression in § 6; but as the men are not to leeward, because no engagement is now supposed, put $\frac{cos.\,s.\,b\,P}{rad.} = o$, and $M = \frac{sin.\,s.\,a\,Q}{rad.}$; whence the $sin.\,s. = \frac{M.\,rad.}{a\,Q}$, and calculating as before, it will be found that the ship will incline $7^{\circ}\,41'$ at a mean, which by common experience is certainly not too much. And this is an evidence that the area of the sails has a proper proportion to the stability of the ship.

19. It is said in the introduction, that vessels of the same dimensions, and even of the same fulness of body in water, may still possess very different qualities, not only in stability, but also in sailing; therefore, practice alone is not sufficient to determine the alteration of masts and yards, in such a manner that the momentum of the sails will become equally serviceable to a ship of other qualities, as it is to the first mentioned. These circumstances will be explained more exactly by the following instance. Suppose a different ship of 74 guns from that in which the area of the sails is already found; of the same dimensions as the former, and with the same displacement, and not only the midship frame, but even every corresponding section or frame of equal area with those of the former; the same quantity of ballast, weight of guns, and number of men; the same height of ports above water, and armed in the same manner, &c.; but that the body in water has a different form (yet not unusual); so that the distance between the centre of gravity of the ship and the metacentre, is about one-fifth less than in the former ship, which was 4,22 feet (§ 12): the distance, therefore, between the centre of gravity and metacentre, in this ship $= 4{,}22 - 0{,}84 = 3{,}38$ feet (which difference and more is not unusual in ships of this magnitude); to which the area of the sails is to be found, so that with the same strength of wind, this ship shall not incline more than the former, viz. 7 degrees.

The momentum of the stability of this ship will then be $100500.\,3{,}38 \quad 339690 = a\,Q$, the momentum of the men to

leeward, b P, will be the same as before = 16560. If the momentum of the power of the sails is put = M, then we have

$$M = \frac{sin.\ s.\ a\ Q}{rad.} - \frac{cos.\ s.\ b\ P}{rad.}\ (\S\ 6);$$

$$\begin{array}{lcl}
\text{Log. } sin.\ 7^\circ & = & 9{,}0858945 \\
\text{Log. } 339690 & = & 5{,}5300828 \\
\hline
 & & 14{,}6159773 \\
\text{Log. } rad. & = & 10{,}0000000 \\
\hline
 & & 4{,}6159773 = 41303 \\
\text{Log. } cos.\ 7^\circ & = & 9{,}9967507 \\
\text{Log. } 16560 & = & 4{,}2190603 \\
\hline
 & & 14{,}2158110 \\
\text{Log. } rad. & = & 10{,}0000000 \\
\hline
 & & 4{,}2158110 = 16434
\end{array}$$

Momentum of the power of the sails M = 24869

which divided by $\frac{1}{59{,}56}$ (§ 5) becomes equal to 1481198.

When the same expression is used as as in § 11, we have $40{,}213.\ x^2 + 2{,}4986\ x^3 = 1481198$; and when the value of x is found in the same manner as in § 13, it will be found that $x = 79{,}0$, which is the breadth of the lower edge of the main top-sail.

The breadth of the lower edge of the main top-sail in the former ship was = 82,29; whence the breadth of the lower edge of the main top-sail in this ship is 10,29 feet less.

By calculating as in § 15, the length of the masts and yards will be found; but for the present, the lengths may be found in the following manner:

The length of the variable part of the main-mast belonging to the former ship is CD = 55,93

$$\begin{array}{rl}
DE = & 11{,}57 \\
EQ = & 14{,}79 \\
\hline
 & 82{,}29
\end{array}$$

and this will be in proportion to the variable part in the last ship, as the breadths of the sails are to one another, that is,

$$89,29 : 79,0 :: 82,29 : 72,8.$$

The invariable part of the mast is = AC	=	16,20
From the water-line to the centre of gravity	=	2,10
From the water-line to the keelson	=	15,75
		34,05
To which add the variable part	=	72,80
The whole length of the mast will be	=	106,85
And the whole length of the mast of the former ship	=	116,34

The main-mast of this ship is then = 9,49 feet shorter than the main-mast of the former ship; but the area of the sails of the former ship is to the area of the sails of this, as $\overline{89,29}^2$ to $\overline{79,0}^2$, which is as 7973 to 6241, or as 100 to 78,27; and as the area of the sails is in proportion to their stabilities, their inclination, when they sail on a wind, will be the same; and as it ought to be supposed that they make an equal resistance against the water, because the areas of their midship frames, &c. are equal, then the first ship, having a greater area of sails, will sail faster than the last;[1] whence it follows, that if the masts and yards of these two ships had been proportioned by the common rules, either the former would have had too small, or the latter too large masts and yards; wherefore, we may conclude, that by practice alone, the true proportion of masts and yards for ships of the line cannot be found.

20. It is said in the introduction, that there are ships of the line arrived almost to perfection in their rigging, and which have their area of sails in the best proportion to the size and quality of the vessel. It may also be inferred from the same observations, that it was for want of theory, that such ships could not serve as models for other ships. But now since a

[1] If the momentum of the sails of this ship had been the same as in the former, then its inclination by the sails only would have been = 5° 46′, and by the men only, = 2° 48′; and by both these powers together = 8° 34′. Or if the ship was to have the same rigging and sails as the former, but the main and fore top-gallant-sails shortened, then its inclination by the sails only, would have been = 4° 12′, and by the men only, = 2° 48′; and by both these powers together, = 7 degrees. Chapman.

theory is found, by which all ships of the line may attain a proportionable rigging, or area of sails, the surest method will be, when we have a ship of the line that is well-rigged, and that has its area of sails in a good or approved proportion to its stability, to let that ship serve as a model, and to make experiments with it in the following manner: whence such rules may be found, that all other ships of the line may acquire as good a proportion of sails to their stability as the model itself.

When such a ship is completely armed and victualled for five or six months, and before it goes to sea, it ought to be provided with a quadrant of four or five feet radius, marked with degrees and minutes, placed in such a manner that it stands perpendicularly when the ship has no inclination. When the ship has been at sea about a month or six weeks, and it happens that there is a top-sail gale with a smooth sea, it must be ordered to clear ship, and to have every thing placed in the same manner as in an engagement with an enemy, all ports open, and guns out; then haul the wind, trim all sharp, and the sails six points near the wind, place the men regularly[1] at the guns to leeward, and at the small-arms on the gangway or poop; all the rest of the men being placed as usual in an action, but in such a manner that they do not occasion the ship to incline more or less. And, in order that the rule which is sought may be made general for all ships of the line, no other sails should be used than the[2] three top-sails and top-gallant-sails, and the fore top-mast stay-sail and jib, if you please; then observe exactly the number of degrees the ship inclines, which put $= s$. When this is done, the ship should run into harbour, before too much of the provision and water is consumed, so that the situation of the centre of gravity of the ship may not be changed;

[1] It is said *regularly*, because of afterwards finding the common centre of gravity of all these men from the middle line of the ship. Chapman.

[2] The reason that only the top-sails and top-gallant-sails, and not the courses, are to be used in the experiment, is this; that three-deck ships neither can nor ought to have as deep lower-sails, in proportion to their top-sails, as two-deck ships. It would then be necessary to contrive two different rules, the one for two-deck ships and the other for three-deck ships, which ought and can be avoided, because these sails are not always used when the ship is in action,—a least not the main-sail. Chapman.

and as she lies at anchor in smooth water, order the experiment of inclining the ship to be made, as described in the Supplement, in order to find the situation of the centre of gravity of the ship.

All weights must be placed in the same manner now as they were when the experiment was made at sea, so that the centre of gravity may be at the same height now as it was then.

Since the centre of gravity is found by this last experiment, and the distance between this centre and the metacentre is also found by means of the draught of the ship, and when a rigging draught is formed, where all the sails that were used in the experiment are drawn in their proper form, size, and place, then their area and centre of gravity will be known; and thence their momentum from the centre of gravity of the ship must be found, and put = A.

The momentum of the power of the sails will be found in the same manner as in § 13, where all the quantities a, Q, b, P, and s, signify the same, but their value is to be taken from this ship. When the operation is performed in the same manner, the momentum of the power of the sails, M, will be known.

If the co-efficient of M is put $= y$, then $\frac{A}{M} = y$, which will be a constant co-efficient for the momentum of the power of the sails, M, for all ships of the line, as well for those of two decks as of three decks.

Hence we have by experience the real value of $\frac{63}{t.v.}$, § 5 and § 11.

Although the proportion and form of the sails belonging to the ship, which was used as a model, may be different from those given in this treatise, the same algebraical expressions must be used; but the numerical value of the expressions must be conformable to the value which the proportion of the sails belonging to this ship gives. When the calculation is made exactly as before, it will give a general expression to be used for all ships of the line, as in § 13, where x, the breadth of the lower edge of the main-top-sail, will be found.

Thus we have a complete theory, which is to be depended on,

for finding the proportion of the sails, and their momenta, not grounded on hypothesis, but on well-contrived experiments and on practice.

But all this should be managed with judgment. For example, suppose the area of the sails is to be determined for a ship deficient in stability, then allowance ought to be made, that its inclination, when in action, may be about one or one and a half degree more than was determined by the rule, according to circumstances; and we should be satisfied with less stability, rather than lose too much velocity.

Conclusion.—At length we have obtained a theory by which may be found not only how great the area of sails ought to be, in order to give a determined inclination to a ship, but also how much the ship will incline when the area of the sails is given.

By the usual methods of finding the lengths of masts and yards, ships of equal dimensions have had the same area of sails, without any regard to their possessing more or less stability.

Suppose a fleet to consist of ships of the line of different forms under water, but of equal dimensions and equal areas of sails, and that they all sail nearly equally, but that it has this fault, that when some of them have stability enough to make use of their lower tier of guns, the rest of the fleet cannot, at least not without hazard, by reason of deficiency in their stabilities: suppose now that the areas of the sails of these last ships are to be diminished to such a proportion, that these ships, in the same strength of wind, are not to incline more than the other ships, and consequently will carry their guns as well; they will then have this fault, that they do not sail so well now as before. This fleet, consisting of ships of an equal[1] stability, but unequal as to their qualities of sailing, is certainly not better than it was before, when all the ships sailed equally well, but were unequal as to their stability, or quality of using their guns.

Whence it is evident, that a fleet which consists of ships of the line of different or unequal qualities, is very imperfect; but

[1] Or, stability in the same proportion to the moment of the sails.

that fleet is perfect, in which all the ships have an equal stability, or incline equally with the same sails; in which all the ships sail equally well, and can all be worked in the same manner, and with the same ease and facility.

We have found that this can never be gained by any alteration in the area of the sails; the defect lies in the form of the ships themselves: the reason of which is this, that when the draught of a ship of the line is to be constructed, the area of the sails is never considered, but the lengths of the lower-mast and top-mast are taken at hazard, in proportion to the breadth of the ship, and the lengths of the yards in proportion to the length of the ship; without knowing if the stability of the ship is as the product of its length multiplied into the square of the breadth, as it then ought to be, if the momentum of the stability of the ship, is to be in proportion to the momentum of the sails from the centre of gravity of the ship.

The proper consideration of the sails is as necessary for a ship of the line as that of the guns; and as on the weight and situation of the guns chiefly depends the situation of the centre of gravity of the ship, so also is it equally necessary to observe, that on the momentum of the sails chiefly depends the value of the stability which the ship requires. The whole is to be considered as one entire machine; for which reason, all its parts and their properties ought to be conceived and determined at the very commencement of the design of the form of the ship, and nothing allowed to be made arbitrary afterwards, that has any influence either on the stability of the ship, or on the momentum of the sails.

This gives the true reason or ground for the principle that is to be followed, in forming a theory, which is capable of giving to ships of unequal magnitudes, equal qualities; and not till that is accomplished, will a fleet of men-of-war arrive at perfection.

Note. The usual method of proportioning the length of masts and yards for ships of the line, is, as has been said before, from the length and breadth of the ship only; and, consequently, is not founded on true principles. It may, probably, give an agreeable appearance to the ship and rigging together,

but it is not always suitable to the stability of the ship. In my Treatise on Ship-building, page 64, is a general expression[1] for the momentum of the sails for vessels of all magnitudes, and useful for all kinds of rigging, which expression was highly necessary (as not being found any where else that I know of), but for ships of the line it is insufficient. It was therefore necessary to invent and establish another method, founded on a better principle, for finding the length of the masts and yards of ships of the line, which has been written in this manner only for the sake of not escaping my memory; but when I, moreover, considered that it would be useful to be known by others, I was induced to print it in this manner, without any further alteration than a small addition in the introduction; wherefore it has happened, that things of less importance are not in the best order.

If this little treatise deserves to be translated, it will be well if it be performed by those who perfectly understand both languages, and rightly comprehend what is here treated of. I am under the greater necessity of mentioning this, because, in my Treatise on Ship-building, which was translated into French, the translator, amongst other observations, has imagined a fault where none existed: as for instance (I will only mention one of the most consequence), he considers in the expression $\int \frac{2}{3} y^3 \, dx - \overline{a + c}. Q$, page 25, line 6, that the quantity $D - Q$ is neglected because it is not expressed; but it is by using this very quantity that the expression acquired its form.

At first it was $\frac{\int \frac{2}{3} y^3 dx}{D} . \overline{D - Q} - cQ$, which is $=$

$\int \frac{2}{3} y^3 \, dx - \frac{\int \frac{2}{3} y^3 dx}{D} . Q - cQ$, but $\frac{\int \frac{2}{3} y^3 dx}{D} = a$, from

[1] The expression here alluded to is this: Let the displacement of a ship $= D$, the distance from the centre of gravity of the ship to the metacentre $= a$, and the length of the ship from stem to sternpost $= l$; then the moment of the sails $= \frac{35,5}{l^{\frac{1}{3}}} . a \, D$.

which the expression becomes $\int \frac{2}{3} y^3 dx - \overline{a + c}.\ Q$, as before;[1] wherefore the system will not fail, as the translator supposes; but the conclusion drawn from the investigation in that section remains unaltered, and will so continue.

The French observation was afterwards translated into Swedish, and as the Swedish translator (under a feigned name) has considered the French more as a censure than as a mere translation, he had added some remarks of censure of his own. He makes an observation, at page 245, line 24, where it is said: "As the distance through which the body had fallen = $\frac{1}{2}$ foot, we have this proportion, $\sqrt{16,\frac{1}{2}} : \sqrt{\frac{1}{2}} :: 33$: the velocity the body has acquired at the end of the fall, whence

$$\frac{33\sqrt{\frac{1}{2}}}{\sqrt{16\frac{1}{2}}} = \frac{\sqrt{544\frac{1}{2}}}{\sqrt{16\frac{1}{2}}} = \sqrt{33} \text{ feet in a second.}$$

On which the Swedish translator makes the following note:—" This proportion is rightly stated; but, probably, by mistaking the right multiplier, it has happened that the conclusion is wrong; because $\sqrt{16\frac{1}{2}} = 4.08 : \sqrt{\frac{1}{2}} = 0{,}223 :: 33 : x = \frac{33.\ 0{,}223}{4{,}08}$ $= 1{,}8$ feet, which is the velocity, in one second, that the body has acquired in falling the distance of half a foot; consequently, what is said in page 49, line 29, and sequel, ought also to be corrected."

Certainly such a miserable observation, on a thing of such small consequence, does not deserve to be refuted; but as it may happen to be perused by one who is no better calculator than the Swedish translator, I will illustrate what is said, for

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[1] Chapman appears to avoid the force of the objection of Clairbois, whose note does not relate to the first expression, the value of the stability before the augmentation of the displacement, which according to the metacentric measure of stability, is perfectly correct, but to the expression of the stability after the augmentation of the displacement, in which Chapman certainly gives a wrong value of the stability from the new centre of gravity of displacement. See note on this subject by Professor Inman in his translation of this work, in which the effect of an augmentation of displacement is correctly determined in reference to the true measure of stability.

such an one, by stating the same proportion, $\sqrt{16\frac{1}{2}} : \sqrt{\frac{1}{2}} ::$ $33 : x$, wherefore $x = \frac{33.\sqrt{\frac{1}{2}}}{\sqrt{16\frac{1}{2}}}$, and $x^2 = \frac{33.33.\frac{1}{2}}{16\frac{1}{2}} = \frac{33.33}{33}$ $= 33$, whence $x = \sqrt{33}$ as before; so that there is no fault.

The fault committed by the Swedish translator is this: he considers that $\sqrt{\frac{1}{2}} = 0{,}223$, which is wrong, because $0{,}223 =$ $\sqrt{\frac{1}{20}}$ or $\sqrt{0{,}05}$; but $\sqrt{\frac{1}{2}}$ or $\sqrt{0{,}5} = 0{,}707$, &c.

Supplement, taken from the new transactions of the Swedish Academy of Sciences, first quarter of the year 1787, page 48, concerning a true method for finding the height of the centre of gravity of a ship when lying afloat, either completely armed, or quite empty, when the draught by which the ship was built is given; by Fred. H. af Chapman.

To solve the problem, it must first be proved, that in whatever place within a ship, either lower down or higher up, a certain weight is moved a given distance from one side to the other, the inclination of the ship will constantly be the same.

Suppose A, fig. 11, to be the centre of gravity of the ship, about which it makes all its angular motions. Through A draw the horizontal line AD, and the vertical line CB. On CB place several equal weights P, at pleasure, as at B and C, and in the centre of gravity A. From B and C draw the horizontal lines BD and CD, and take BD, CD, and AD, at pleasure, but of equal lengths. Through the centre of gravity A, draw the inclined line *bc*; from any place K on this line, draw a vertical line KL, take A*c*, A*b* = AC, AB. From *c*, A, and *b*, draw *c*O, AM, and *b*N, at right angles to *cb*, and take *c*O, AM, and *b*N, all of the same length, and equal to CD, AD, and BD.

Suppose fig. 11 to represent a transverse section of the ship, and let the weight at A be removed to D, and suppose the ship thereby to acquire the inclination *bc*; the weight P comes then into the place M, and the weights that were in C and B are now in *c* and *b*. Suppose K to be the metacentre of the ship; LK the direction of the water to oppose the inclination

of the ship, with a power Q, equal to its whole weight, or displacement. From M, N, and O, draw the vertical lines ME, NG, and OF, and through *c* and *b*, draw the horizontal lines H*c*F, and *b*I*g*.

The power of the momentum to make the ship incline is then, $\overline{AE + Hc - bI}$. P, and (as it may be compared to a lever of the second order) it will be = AL. Q.

Remove the weight in M to its former place in A, and the ship will resume its upright position. Remove now the weight in C to D, then the ship inclines, so that C*b* takes the situation *cb*, whence the weight P comes into the place O. The momentum of the power to make the ship incline is now $\overline{cF + Hc - bI}$. P, the same as before, because $cF = AE$.

Remove the weight in O to its former place, and the ship again resumes its upright position. Remove the weight in B to D, then the ship inclines, so that C *b* takes the situation *cb*, whence the weight in P, which before was in B, is now in N. The momentum of the power to make the ship incline is now $\overline{bG - bI + Hc}$. P, the same as before, because $bG = cF = AE$.

But as the distances H*c*, I*b*, are not described from the motion of the weight P in the vessel, but merely from the angular motion of the ship, and all other weights in it, about its centre of gravity A, they may be altogether neglected; and, therefore, each of the quantities AE. P, *c*F. P, and *b*G. P, is equal to to AL. Q.[1] Whence it follows, *that in whatever place in a ship, either in the hold or higher up, a certain weight is moved a given distance from one side to the other, the inclination of the ship will be constantly the same;* which was to be demonstrated.

But as every one may not, by this demonstration, be en-

[1] What is said here by the author cannot be admitted to be strictly a proof of this proposition; its truth, however, is evident on these principles of mechanics, that in any system of weights, if any one of them is moved in a given direction a certain distance, the centre of gravity of the system is always moved in the same direction a distance inversely as the sum of the weights to the weight moved; and as in this case the weights moved are equal, the distance the centre of gravity of the system is moved will be always the same; and that in any floating body the removal of its centre of gravity a certain distance in a given direction, always causes it to incline equally from its former state of equilibrium.

tirely convinced of the truth of this proposition, perhaps the following experiment may more satisfactorily evince its truth.

For this purpose cause a box, or small ponton, fig. 12, to be made, about 18 or 20 inches long, and 4 inches deep; erect two posts, DF, CE, on the sides, and lay the two shelves, H and G, between them, parallel to the bottom AB; set a mark I in the middle of the bottom, and perpendicularly over it mark K, L, on the shelves. Mark M, N, and O, equally distant from I, K, and L; place three equal weights in the middle of the box, exactly on the marks I, K, and L; place the box in water, and be careful that it floats upright. Move the weight at I to M, and the box will incline; then move it back to its former place, and do the same with the other weights, and it will be found that the box, by each of these changes, will acquire the same inclination.

We have, therefore, two demonstrations, the one by theory, and the other by experiment. This problem could have been demonstrated in a more concise manner; but I have been the more prolix in making it in every possible manner intelligible and obvious, because seafaring men, of all nations, are generally of opinion, that if two equal weights, one placed on the lower-deck, and one on the quarter-deck, are to be moved an equal distance from one side to the other, that the ship inclines more by the weight moved on the quarter-deck, than by the weight moved on the lower-deck.

To apply this in finding the position of the centre of gravity of a ship of the line when completely armed:

1. Let the ship's company be separated, and placed on the decks, quarter-deck, and forecastle, either at the middle, or divided on both sides of the ship, so as not to cause the ship to incline. Let all the guns be run out above and below; place the quadrant, by which the inclination of the ship is to be measured, and observe the ship's draught of water forward and abaft.

2. Draw a vertical line on each side of the gun-carriages, and mark its place on the deck.

3. With part of the ship's company haul the guns, either on one or both decks, as far in as the hatches and other hindrances will allow, some more and others less, till the ship has acquired an inclination of about six or eight degrees. Nail cleats

against the trucks of the carriages, that they may stand fast, and not slide more to leeward; let the men then take their former stations, and observe exactly how many degrees and minutes the ship inclines.

4. Number the guns, and measure the distance that each of them has been moved.

5. Take the weight of each gun, carriage, breeching, and coins, &c., that are connected with the gun when moved, and reduce this weight to cubic feet of sea-water.

Calculate in the following manner: multiply the weight of each gun, &c., into the distance moved, which is the momentum of that gun. Divide the sum of all those momenta by the weight of all the guns moved, thence we have the mean distance of all the guns moved, which put $= a =$ AD.

Let the whole weight of the ship, or its displacement to the outside of the planks $=$ Q, the sum of all the weights which caused the ship to incline $=$ P, number of degrees the ship inclined $= s$, AE $= y$, AL $= x$, and AK the distance between the centre of gravity of the ship and the metacentre $= w$: then

$y = \dfrac{a.\ cos.\ s}{rad.}$; and AL. Q $=$ AE. P; that is, $xQ = yP$; whence

$x = \dfrac{yP}{Q} = \dfrac{a.\ P.\ cos.\ s}{2\ rad.}$; and as $w = \dfrac{x.\ rad.}{sin.\ s}$, we have $w =$

$\dfrac{a.\ P.\ cos.\ s}{Q.\ sin.\ s}$.

Suppose $s = 7°\ 15'$, $a = 16$ feet, P $= 2800$ cubic feet of water, and Q $= 77000$ cubic feet of water.

$$
\begin{array}{lcl}
\text{Log. } cos.\ 7°\ 15' & = & 9,9965138 \\
\text{Log. } sin.\ 7°\ 15' & = & 9,1010558 \\
\hline
 & & 0,8954580 \\
\\
\text{Log. } 16 \quad - & = & 1,2041200 \\
\text{Log. } 2800 \quad - & = & 3,4471580 \\
\hline
 & & 5,5467360 = 352150 = \left\{ \textit{Momentum of the stability of the ship.} \right. \\
\text{Log. } 77000 \quad - & = & 4,8864907 \\
\hline
 & & 0,6602453 = 4,573 = w
\end{array}
$$

consequently, KA, the distance from the metacentre to the centre of gravity of the ship, = 4,573 feet.

If it is found, from the draught of the ship, that the distance from the upper water-line to the metacentre is, for instance, 5,75 feet; then the centre of gravity of the ship, and of every thing that is in it, is = 5,75 − 4,573 = 1,177 feet above the same water-line.

When such experiments are designed to be made, the carriages ought to be weighed before they are brought on board, as also all the implements belonging to the guns which are moved; the guns have generally their weights marked on them.

As this method of finding the centre of gravity of a ship is simple and easy, as well as accurate, if rightly executed, requires but little time, and is not attended with any expense; considering the knowledge which may be thereby acquired, experiments ought to be made with all kinds of ships of war when armed. By these means the art of ship-building will advance much faster to its perfection than it has hitherto done.

To render this little treatise, for finding the area of sails for ships of the line, useful to an English reader, the following ought to be known:—

A cubic foot of sea-water is supposed, in this work, to weigh 63 pounds.[1]

1000 pounds, Swedish, = 937 pounds avoirdupois, English.
1000 feet, Swedish, = 975 feet, English.
1000 square feet, Swedish, = 950,62 square feet, English.
1000 cubic feet, Swedish, = 926,86 cubic feet, English.

Whence $\frac{937 \cdot 63}{926,86} = 63,69$, which is the weight of an English cubic foot of sea-water in pounds avoirdupois.

[1] As authors seldom agree in these proportions, between different nations, I am not sure that those given here are entirely to be relied on, but they cannot be far from the truth; besides, as the weight of a cubic foot of sea-water must certainly be known in England, the error can be easily corrected. Chapman.

The power of the wind on a square foot, English, is $= \frac{937.v}{950.62} = 0{,}986.v$ pounds avoirdupois, whence we have 2,29, or v (§ 4) = 2,26 pounds, and the general expression for the momentum of the sails (§ 11) will be $d.2{,}4823.x^2 + 2{,}4986\,x^3 = \frac{63{,}69.\,M}{0{,}4619.\,v}$.

From the above proportions, the length of the 74-gun ship, between the perpendiculars of the stem and sternpost (§ 12), will be $184.0{,}975 = 179{,}4$ feet, English.

Breadth moulded	- -	$49\frac{5}{8}.0{,}975 = 48{,}4$	feet.
Draught of water abaft	-	$22.0{,}975 = 21{,}45$	„
Ditto forward	-	$20\frac{1}{2}.0{,}975 = 20.0$	„
Ports above water	- -	$6\frac{5}{8}.0{,}975 = 6\frac{5}{3}$	„

Its displacement, to the outside of the planks, is = $100500.0{,}92686 = 93149 = Q$, and $4{,}22.0{,}975 = 4{,}114 = a$, the weight of the men $= 2{,}5.409 = 1023 = P$, $b = 14{,}625$, $bP = 14961$, $aQ = 383215$, and $d = 15{,}795$.

By the operation in § 13, $M = 31857$; and as $v = 2{,}26$, we have $\frac{63{,}69}{0{,}4619.\,v} = \frac{63{,}69}{0{,}4619.\,2{,}26} = 61{,}012$. Whence $15{,}795.2{,}4823.x^2 + 2{,}4986.x^3 = 61{,}012$, or $39{,}208\,x^2 + 2{,}4986.x^3 = 1943659$; using the method given in the same section, we have $x = 87$ = the breadth of the lower edge of the main top-sail; hence it will be found, that the whole length of the main yard is = 95,7 feet, of the top-sail-yard = 76 feet, the length of the main top-mast, from the edge of the fid, = 65,77 feet, and the whole length of the main-mast = 113,38 feet; that is, 27,54 feet from the keelson to the upper side of the upper deck, and 85,84 feet from the upper deck to the top-end of the mast.

From the observation near the end of section 20, it may be seen, that we are not restricted to any certain form of sails, nor to a certain proportion of the area of the sails of one mast in comparison with the others, but that these may vary as experience and reason dictate, only observing a similarity between the top-sails and top-gallant-sails; the moment of the sails

will, nevertheless, be in proportion to the stability of the ship.

Perhaps it will be thought that this theory depends too much on practical determinations, but it will be found that it cannot be otherwise. For example, it is the experienced seaman who knows best, if the square sails ought to be more or less tapering upwards; if they ought to have more or less depth in proportion to their breadth; with many other particulars which are not determinable by theory. By the help of such information, theory determines the absolute quantities themselves; that is, the breadth of the main top-sail below, and thence all the other proportions, conformably to the experience of the seaman, and, at the same time, in proportion to the stability of the ship.

A theory which does not agree with practice, is undeserving the name of theory.

ART. IV.—*Account of the Number and Description of the Artillery, Projectiles, Small-arms, and Ammunition, which form the Establishment of those Articles on board the different Classes of Ships composing the French Navy.* (*From the Annales Maritimes.*)

ARTILLERY—in classes of vessels, which, having been constructed after designs that are no longer approved—will only continue to form a part of the naval force, for the term of the duration of the present ships.

1.—*Ships of three decks, carrying* 120 *guns.*

On the lower-deck, thirty-two 36-pounder guns.[1]
On the middle-deck, thirty-four 24-pounder guns.
On the upper-deck, thirty-four 36-pounder carronades.
On the quarter-deck and forecastle, sixteen 36-pounder carronades and four long 18-pounder guns.

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[1] The comparative English calibres of the French 36, 30, 24, 18, 12, and 6-pounder guns, are respectively 38.8, 32.4, 26, 19.5, 13, and 6.5.

For the boats, the tops, and the poop, one 24, and one 12-pounder carronade, four large swivels (*Perrier*[1]), and eight small ones (*Espingole*[1]).

2.—*Ships of three decks, carrying* 110 *guns.*

On the lower-deck, thirty 36-pounder guns.
On the middle-deck, thirty-two 24-pounder guns.
On the upper-deck, thirty-two 36-pounder carronades.
On the quarter-deck and forecastle, twelve 36-pounder carronades, and four long 18-pounder guns.
For the boats, &c., the same as for the 120-gun ship.

3.—*Ships carrying eighty-six guns, called* 80-*gun ships.*

On the lower-deck, thirty 36-pounder guns.
On the upper-deck, thirty-two 24-pounder guns.
On the quarter-deck and forecastle, twenty 36-pounder carronades, and four long 18-pounder guns.
For the boats, &c. the same as for the 120-gun ship.

4.—*Ships carrying* 82 *guns, called* 74-*gun Ships.*

On the lower-deck, twenty-eight 36-pounder guns.
On the upper-deck, thirty 18-pounder guns.
On the quarter-deck and forecastle, twenty 36-pounder carronades, and four long 18-pounder guns.
For the boats, &c. one 18, and one 12-pounder carronade, four large swivels, and eight small ones.

5.—*Razees, carrying* 58 *guns,* 36-*pounders on the main-deck.*

On the main-deck, twenty-eight 36-pounder guns.
On the quarter-deck and forecastle, twenty-eight 36-pounder carronades, and two long 18-pounder guns.
For the boats, &c. the same as for an 82-gun ship.

6.—*Frigate carrying* 58 *guns,* 24-*pounders on the main-deck.*

On the main-deck, thirty 24-pounder guns.
On the quarter deck and forecastle, twenty-six 24-pounder carronades, and two short 18-pounder guns.

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[1] Both these species of swivel are of the calibre of one pound, but the weight of the *Perrier* is 187 pounds, while that of the *Espingole* is only about 44 pounds.

For the boats, &c. two 12-pounder carronades, four large swivels, and eight small ones.

7.—*Frigate carrying* 46 *guns,* 18-*pounders on the main-deck.*

On the main-deck, twenty-eight 18-pounder guns.

On the quarter-deck and forecastle, sixteen 24-pounder carronades, and two short 18-pounder guns.

For the boats, &c. two 12-pounder carronades, four large swivels, and eight small ones.

8.—*Corvette, with quarter-deck and forecastle, carrying* 28 *guns.*

On the main-deck, twenty 24-pounder carronades.

On the quarter-deck and forecastle, six 12-pounder carronades, and two 12-pounder guns.

For the boats, &c. four large swivels, and six small ones.

9.—*Corvette, flush-decked, carrying* 20 *guns.*

Eighteen 24-pounder carronades, two 6-pounder guns, four large swivels, and six small ones.

10.—*Brig carrying* 18 *guns.*

Sixteen 24-pounder carronades, two 8-pounder guns, four large swivels, and six small ones.

11.—*Brig carrying* 16 *guns.*

Fourteen 24-pounder carronades, two 8-pounder guns, four large swivels, and six small ones.

12.—*Small Brig, and large Schooner.*

From eight to ten 18-pounder carronades, four large swivels, and two small ones.

13.—*Small Schooner, Cutter, Lugger, and Advice-Boat.*

From two to six 12-pounder carronades, two large swivels, and two small ones.

14.—*Gun-Boat.*

Two 18-pounder carronades, two 12-pounder guns, four large swivels, and two small ones.

Vessels constructed after new Designs, and of which the Navy will eventually be wholly composed.

15.—*First-rate Line-of-battle Ship.*

On the lower-deck, thirty-two long 30-pounder guns.

On the middle-deck, thirty-four short 30-pounder guns.

On the upper-deck, thirty-four 30-pounder carronades.

On the quarter-deck and forecastle, sixteen 30-pounder carronades, and four long 18-pounder guns.

For the boats, &c. one 18-pounder, and one 12-pounder carronade, four large swivels, and eight small ones.

16.—*Second-rate Line of-battle Ship.*

On the lower-deck, thirty-two long 30-pounder guns.

On the upper-deck, thirty-four short 30-pounder guns.

On the quarter-deck and forecastle, thirty 30-pounder carronades, and four long 18-pounder guns.

For the boats, &c. the same as for a first-rate ship.

17.—*Third-rate Line-of-battle Ship.*

On the lower-deck, thirty long 30-pounder guns.

On the upper-deck, thirty-two short 30-pounder guns.

On the quarter-deck and forecastle, twenty-four 30-pounder carronades, and four long 18-pounder guns.

For the boats, &c., the same as for a first-rate ship.

18.—*Fourth-rate Line-of-battle Ship.*

On the lower-deck, twenty-eight long 30-pounder guns.

On the upper-deck, thirty short 30-pounder guns.

On the quarter-deck and forecastle, twenty 30-pounder carronades, and four long 18-pounder guns.

For the boats, &c. the same as for a first-rate ship.

19.—*Frigates of the first class, carrying* 60 *guns.*

On the main-deck, thirty long 30-pounder guns.

On the quarter-deck and forecastle, twenty-eight 30-pounder carronades, and two long 18-pounder guns.

For the boats, &c. the same as for a first-rate ship.

20.—*Frigates of the second class, carrying* 52 *guns.*

On the main-deck, twenty-eight 24-pounder guns.

On the quarter-deck and forecastle, twenty-two 24-pounder carronades, and two short 18-pounder guns.

For the boats, &c., two 12-pounder carronades, four large swivels, and eight small ones.

21.—*Frigates of the third class, carrying* 46 *guns.*

On the main-deck, twenty-eight 18-pounder guns.

On the quarter-deck and forecastle, sixteen 30-pounder carronades, and two short 18-pounder guns.

For the boats, &c., the same as for the frigates of the second class.

22.—*Corvette, with quarter-deck and forecastle, carrying* 32 *guns.*

On the main-deck, twenty 30-pounder carronades, and four short 18-pounder guns.

On the quarter-deck and forecastle, eight 30-pounder carronades.

For the boats, &c., one 12-pounder carronade, four large swivels, and six small ones.

23.—*Corvettes, flush-decked, carrying* 24 *guns.*

Twenty 30-pounder carronades, and four short 18-pounder guns.

24.—*Large Brig, carrying* 20 *guns.*

Eighteen 24-pounder carronades, and two short 18-pounder guns.

25.—*Corvette, Advice-Boat.*

Sixteen 18-pounder carronades, and two 8-pounder guns.

26.—These last three classes will also have,

For their boats, &c., one 12-pounder carronade, four large swivels, and six small ones.

27.—*Schooner-Brig, or Advice-Boat.*

Sixteen 18-pounder carronades, four large swivels, and four small ones.

28.—*Gun-Brig.*

Six 18-pounder carronades and two 8-pounder guns, four large swivels and four small ones.

29.—*Schooner.*

Six 18-pounder carronades, four large swivels, and two small ones.

Ships of Burthen.

30.—*Corvette and Transport, of* 800 *tons and upwards.*

Twenty 24-pounder carronades, and two 8-pounder guns.

31.—*Store Ship, of from* 600 *to* 400 *tons.*

Sixteen 18-pounder carronades, and two 8-pounder guns.

32.—*Store Ship, of from* 400 *to* 260 *tons.*

Twelve 18-pounder carronades, and two 6-pounder guns.

33.—These last three classes have, besides this, four large swivels and six small ones.

34.—*Store Ship, of* 260 *tons and below.*

Two 6-pounder guns, two large swivels, and two small ones.

35.—The above establishments for vessels of burthen, and of transport, are to be considered as limits which are not, in any case, to be exceeded, but within which their force is to be restricted whenever circumstances may permit.

PROJECTILES.

36.—*Round Shot.*

For Line-of-battle Ships and Frigates.

Seventy-five for each gun.
Thirty for each carronade of a similar calibre with the guns.
Forty for each carronade of a different calibre.

For Vessels of the smaller classes.

Forty-five for each gun, and forty for each carronade.
Forty for each swivel, in ships of all classes.

37.—*Double-headed Shot.*

Five for each gun, for all classes of ships.

38.—*Grape Shot for Cannon.*

Ten for each gun on the lower-decks of all line-of-battle ships; and also, for each gun on the middle-decks of three-deckers.

Fifteen for each gun on the upper-decks of line-of-battle ships, and the main-decks of frigates.

Twenty for each gun on the quarter-decks of line-of-battle ships and frigates.

Twenty for each gun in all the smaller classes of ships.

39.—*Grape Shot, with large Balls, for Carronades.*

Twenty-five for each carronade, in line-of-battle ships and frigates.

Thirty-five for each carronade, for the boats of these classes.

Fifteen for each carronade, in the smaller classes of ships.

40.—*Grape Shot, with small Balls, for Carronades.*

Five for each carronade in line-of-battle ships and frigates.

Fifteen for each carronade for the boats of these classes.

Five for each carronade in the smaller classes of ships.

41.—*Grape or Canister for Swivels.*

Twenty for each, in all classes of ships.

The Minister Secretary of State for the Marine and Colonies,

Baron Hyde de Neuville.

Signed and approved, Paris, Sept. 18th, 1828.

Establishment of the Number and Description of Weapons to be furnished to the several Classes of Vessels.

1. The several descriptions of weapons are to be delivered to ships of various classes, as shown by the following table.

CLASS OF VESSEL.	Muskets.	Carbines.	Pistols.	Sabres. Infantry	Sabres. Boarding	Tomahawks.	Boarding Pikes.[1]
OLD CLASSES OF SHIPS.							
Line-of-battle ship of 120 guns . . .	250	40	250	40	210	120	120
do. do. 110 do. . . .	220	36	220	36	184	100	100
do. do. 86 do. called 80	190	34	190	34	156	90	90
do. do. 82 do. do. 74	160	30	160	30	130	80	80
Razee of 52 guns	120	26	120	26	94	60	60
Frigate of 58 do.	100	24	100	24	76	50	50
do. 46 do.	90	20	90	20	70	40	40
Corvette of 28 do.	80	10	80	10	70	30	30
do. 20 do.	50	8	50	8	42	24	24
Brig of 18 do.	40	8	40	8	32	20	20
do. 16 do.	36	8	36	8	28	20	20
Small brig and large schooner . . .	30	8	30	8	22	16	16
Small schooner, cutter, lugger, &c. . .	12	6	12	4	8	10	10
Gun-boat	12	6	12	4	8	10	10
PRESENT CLASSES OF SHIPS.							
Line-of-battle ship first-rate	250	40	250	40	210	120	120
do. do. second-rate . . .	220	36	220	36	184	100	100
do. do. third-rate	200	34	200	34	166	90	90
do. do. fourth-rate . . .	160	30	160	30	130	80	80
Frigate. First class	110	26	110	26	84	60	60
do. Second class	100	24	100	24	76	50	50
do. Third class	90	20	90	20	70	40	40
Large corvette	80	12	80	12	68	30	30
Small corvette	70	10	70	10	60	26	26
Large brig	50	8	50	8	42	24	24
Corvette advice-boat	50	8	50	8	42	24	24
Schooner-brig, or advice-boat	36	8	36	8	28	20	20
Gun-brig	20	6	20	6	14	12	12
Schooner	18	6	18	6	12	12	12
Corvette and transport, of 800 tons . .	60	12	60	12	48	24	24
do. do. 600 to 400 tons	40	10	40	10	30	20	20
do. do. 400 to 260 do.	30	10	30	10	20	16	16
do. do. 260 and below	14	6	14	6	8	10	10

[1] If on any account, the number of men composing the crews of any of the before-mentioned ships should be altered, the

[1] These two articles are only applicable to flush-decked vessels: for line-of-battle ships, frigates, and the large corvettes having a quarter-deck and forecastle, directions will be given by the Minister of the Marine and Colonies, when the occasions occur.

quantity of muskets and pistols is to be fixed at one half the number of men on board, including officers: then the quantity of the various other species of weapons will preserve the same proportion in number to that of the muskets or pistols as before the alteration in the crew.

[1] The scale fixed in the preceding paragraph, may be also used in determining the proportion of weapons of various sorts to be furnished to any other species of vessel.

When a ship is manned either wholly or in part by men belonging to the *équipages de ligne*, these men will retain their arms, and an equal number must be deducted from the quantity to be furnished the ship, as shown in the preceding directions.

The Minister Secretary of State for the Marine and Colonies,

(*Signed*) Baron Hyde de Neuville.

Approved, Paris, Feb. 16th, 1829.

Establishment of the quantity of Powder to be delivered to Ships of various classes.

1.—The quantity of powder to be delivered to each ship is to be determined in the following manner.

For carronades.

As many charges, as there are round and grape shot.

For cannon, and for the swivels.

As many charges, as there are round shot.

2. The charges of powder for the cannon, are to be of two different weights.

One-fifth the total number of charges are to weigh, each, one-third the weight of the ball; the remaining four-fifths are to weigh only one-fourth the weight of the ball.

3. The weights of the charges are to be, for cannon:—

Calibre of the gun.	36	30	24	18	12	8	6
	kilogr.	kilogr.	kilogr.	kilogr.	kilogr.	kilogr.	kilogr.
⅓ the ball	5.88	4.90	3.92	2.94	1.96	1.31	.98
¼ the ball	4.40	3.67	2.94	2.20	1.47	.98	.73

4. The charges for the carronades, and for the swivels, will remain as they are at present, that is,

Calibre of the Carronades.					Large Swivels.	Small Swivels.
36	30	24	18	12		
kilogr.	kilogr.	kilogr.	kilogr.	kilogr.	kilogr.	kilogr.
1.96	1.59	1.35	1.10	.73	.18	.05

5. Fine powder for priming, will be delivered in the proportion of one kilogramme (2,2 lbs. avoirdupois) for two hundred primings.

6. The charge of powder for small-arms will be as follows :—

For a musket - - ,0125 kilogrammes.

For a carbine or pistol - - ,0083 ditto.

For all these arms, the balls will be of the weight of twenty to the pound.

7. The cartridges for the small-arms will be ready made, and delivered on board in the proportion of one hundred and twenty for each musket and carbine, and twenty for each pistol.

In consequence of this, neither cartridge-paper, balls, or loose musket-powder, will in future be delivered.

8. The quantity of inferior powder, for salutes, &c. &c., will vary according to the station of the ship.

9. The whole of the powder will be enclosed in copper cases, hermetically shut.

The fine powder for priming, and the inferior powder, will be in grain. The powder for the artillery and small-arms, in cartridges.

10. Whenever it may be impossible to furnish these copper cases to a ship, the powder is to be delivered as at present; that is, two-thirds in grain, and the remaining third in cartridges.

The Minister Secretary of State for the Marine and Colonies,

(*Signed*) Baron HYDE DE NEUVILLE.

Approved, Paris, Feb. 16*th*, 1829.

Establishment, of the description and quantity of Powder and Ball to be delivered to Ships of all classes, for the purpose of exercising the Crews.

1. In future, the powder and balls used for exercise are to be similar to those used in actual combat.

2. The number and description of artillery to be selected for exercise on board line-of-battle ships and frigates, are to be as follow :—

	Cannon.				Carronades.		
	Calibre.				Calibre.		
OLD CLASSES OF SHIPS.	36	30	24	18	36	30	24
Line-of-battle ship of 120 guns . .	—	—	5	2	5	—	—
Ditto ditto 110 do. . .	—	—	5	2	4	—	—
Ditto ditto 86 do. . .	—	—	5	2	2	—	—
Ditto ditto 82 do . .	—	—	—	6	2	—	—
Razee of 52 guns	2	—	—	1	3	—	—
Frigate of 58 do.	—	—	2	1	—	—	3
Ditto 46 do.	—	—	—	3	—	—	2
NEW CLASSES OF SHIPS.							
Line-of-battle ship, first-rate . .	—	5	—	2	—	5	—
Ditto ditto second-rate .	—	5	—	2	—	3	—
Ditto ditto third-rate . .	—	5	—	2	—	2	—
Ditto ditto fourth-rate .	—	4	—	2	—	2	—
Frigate, first class	—	2	—	1	—	3	—
Ditto second class	—	—	2	1	—	—	2
Ditto third class	—	—	—	3	—	2	—

3. The total quantities of powder and of projectiles to be delivered to vessels of all classes, may be determined from the tables[1] which accompany these directions.

4. When vessels which are not included in this table require ammunition for exercise, the quantity is to be determined by a proportion which will allow each captain and second captain of a gun to fire fifteen times in a year. In all classes of ships below frigates, the proportion is to be estimated at twenty times in a year.

The charges of powder are to be, for cannon, one-fourth the weight of the bullet; and for carronades, the same as those determined in the 4th article of the preceding order, (page 74.)

5. When ships are stationed either in the roadsteads of the ports of France, or in the French colonies, the commanders are directed to exercise the crews weekly, or fortnightly, as may be found necessary, from the progress made by the men, the exercise not to exceed three discharges for each captain and second captain of a gun.

The ammunition expended in this manner is to be replaced immediately, in order that there may be no intermission in this practice.

SMALL-ARMS.

6. The cartridges for exercising small-arms are to be delivered in the proportion of fifty for each musket and carbine; that is, forty ball cartridges and ten blank cartridges.

7. The ball cartridges will be similar in every respect to those delivered for actual combat, but the blank cartridges will be made of inferior powder; the quantity for a charge will be,

For a musket - - ,0083 kilogrammes.
And for carbines - - ,00625 ditto.

8. This powder, both for the artillery and the small-arms, will be delivered in copper cases, hermetically closed, similar to the powder delivered for actual combat.

The fine powder for priming, in grain.

The powder for the artillery and small arms, in cartridges.

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[1] The tables here mentioned contain the total quantities of powder, ball, &c. &c., estimated from the directions which are here given, to facilitate the delivery of the various stores to ships fitting out.

9. Whenever it is not possible to furnish these copper cases to a ship, the powder is to be delivered, one-third in cartridges, and the remaining two-thirds in grain.

The Minister Secretary of State for the Marine and Colonies,

(Signed) Baron Hyde de Neuville.

Approved, Paris, 19*th Feb.* 1829.

Art. V.—*Observations on a Ship's Rolling, and the means of rendering that motion more easy when it is violent. By* John Wilson, Esq. *of the Navy Office, London.*

The subject of the rolling motion in ships, has been treated of by many eminent writers on naval construction; and, as far as the various weights which compose, or that are placed in a ship, affect her rolling, when that operation has commenced, every thing has been explained which is necessary to a clear understanding of the subject. The first cause of a ship's rolling is generally stated to be the impulse of a sea on her side, in a direction pointing above her centre of gravity. That such an impulse would heel the ship until her stability overcame it, is certain; but it is probable the principal effect of such a blow would be the shock it would cause; and the ship would do little more than recover her former position; so that her rolling motion would be trifling. Chapman, in his chapter on rolling and pitching, only takes this view of the cause of a ship's commencing rolling into consideration, although he says, and the testimony of all seamen confirms his observation, that "the rolling seldom takes place except when the ship sails before the wind, and she rolls more when a short time previously the wind had blown from another quarter; as the waves continue to come in this direction, the vessel rolls, although there does not appear to be much swell." It therefore appears, that the impulse, or blow of a sea, is not the chief cause of a ship's beginning to roll, but that it arises from the undulations of the waves; and in the succeeding pages of this paper it is proposed

to investigate this cause, and to add some observations on the means of diminishing uneasy and deep rolling.

A ship's rolling commences the moment a wave rises on one side and sinks on the other side of her; let us suppose the swell has altered from the horizontal line AB, fig. 13, to the line *ab*, the centre of displacement D would be removed to *d*, the displacement pressing perpendicularly upwards in the direction *dg*, the centre of gravity G not being in this line of support, the ship would begin to turn round her axis of rotation (which in this case is represented as the metacentre) until her centre of gravity meets the line of support *dg*, in *g*, in which position the wave will have no more power to turn her round. It is proper to observe here, that the inclination of the side of the wave on which the ship floats is continually, and by imperceptible degrees, changing from an horizontal position to its greatest angle of inclination, and *vice versa;* therefore the force to turn the ship comes on by slow degrees; and, long before she has arrived at that angle of rolling, which even a small inclination of the side of a wave would give, an opposing wave arises on the other side of the ship, and prevents her further depression. This operation is not at all like the effort of an impulse which, by raising her centre of gravity, and then precipitately leaving her, would let her fall down suddenly, and thus cause a jerking motion.

The reader will readily perceive that the strength of the tendency of a ship to commence rolling, will be determined by the distance of the centre of gravity from the metacentre, compared with the distance of the centre of displacement from the metacentre. To prove how this view of the subject is borne out by facts, those centres, namely, the centres of gravity, the metacentre, and the centre of displacement, have been accurately calculated for a great variety of ships; they are exhibited in figures 13, 14, 15, 16, 17, and 18, which are drawn principally to show the tendencies which the several classes of ships in the British navy have to roll. AB is an horizontal line, and is the loadwater line of the ships when in an upright position; *ab*, *ab*, &c., are all drawn to an angle of 15° from the horizontal line, being the inclination which the side of the wave is supposed to have assumed; D, D, &c., the centres of displacement when the surface of the sea is level; *d*, *d*, &c., the centres of

displacement when the side of the wave has the above inclination; G, G, &c. the centres of gravity when the ships are upright, and *g*, *g*, &c. the same centre when the wave has ceased inclining the ship; M, M, &c., the metacentres. The degrees of inclination show the strength of the tendency of the several classes of the ships to commence rolling; fig. 13, shows this tendency in the Caledonian, of 120 guns; she was the only ship of that class, when these calculations were made, whose sailing qualities had been tried. Her tendency to roll is the greatest of all the classes, its representative number may be taken at 46, the number of degrees she would heel on the side of a wave, if it had a permanent inclination of 15°. She is reported, by her officers, in their official communications, "to roll in the trough of the sea *quite easy*." Fig. 14, exhibits the rolling tendency of the class of 74-gun ships, of which 40 were built from the same draught; and the three centres, that of gravity, of displacement, and the metacentre, were calculated from the average draught of water, weights, &c. of the following ships of that class, taken promiscuously: Armada, Cressy, Poictiers, Conquestadore, Glocester, Blenheim, Rippon, and Clarence. The reports from their officers state that they rolled "*tolerably easy*" in the trough of a sea; their tendency to commence rolling is indicated by 31½°, being one third less than that of the Caledonia, arising from the distance between their metacentres and their centres of gravity, being greater in proportion to the distance between their metacentres and their centres of displacement, than is the case in that ship. The next figure (15), shows the effect of the wave on two frigates, of 46 guns, built from a draught similar to that of the French *Hebe;* their names were Leonidas and Shannon; their tendency to commence rolling is as 26½°; they were reported to roll "*deep without jirking*." Fig. 16 shows the like effect on a class of brigs, almost innumerable, those of 18 guns; eight were taken, without selection, for the calculations; namely, the Alert, Scylla, Castilian, Persian, Charybdis, Crane, Espiegle, and Pelican; their rolling in the trough of the sea is stated to be *easy;* their disposition to roll is indicated by 24½°. Fig. 17, exhibits the tendency to roll, of the brigs of 10 guns, a class nearly as numerous as that

of the brigs of 18 guns. They are stated to roll "*middling easy*," and their aptness to commence rolling is shown by $21\frac{1}{2}°$. The last in the series, fig. 18, represents the rolling of the Anson, of 38 guns; she had been a 64-gun ship, and was cut down to a frigate; the nmber of degrees showing her tendency to commence rolling is $18\frac{1}{2}°$, and her rolling was exceedingly violent. She was cut down in the year 1794; and although, in all other maritime states, the science of naval construction was well understood, yet so culpably ignorant were the English constructors, that this operation, so well calculated, when properly conducted, to produce a good ship, was a complete failure. Seven feet of the upper part of the topsides, together with a deck and guns, making about 160 tons, were removed, by which her stability was greatly increased; but, by a complete absurdity, the sails were reduced one-sixth in area. In her first voyage the rolling was so excessive, that she sprung several sets of topmasts. To mitigate this evil, in 1795 her masts and yards were increased to their original size; but as there was no decrease of ballast she was still a very uneasy ship, and, as a necessary result, her wear and tear were excessive.

Other sixty-fours were cut down, masted, and ballasted in exactly the same manner, and, it need scarcely be added, experienced similar misfortunes; and although they were improved by enlarging their masts and yards, they were still bad ships. Had their transformations been scientifically conducted, a class of frigates would have been continued in the navy, capable from their size of coping with the large American frigates; and thus the disasters we experienced in the late war, from the superior force of the frigates of that nation, would, without doubt, have been not merely avoided, but turned into occurrences of a quite opposite character.

By referring to the series of figures from 13 to 18, and comparing them with the actual rolling of the ships, the accounts of which are taken from official documents furnished by their commanders, it will be seen that the greater the tendency to commence rolling, indicated by the representative numbers, the easier was the rolling motion; but as there is another condition, when a ship has commenced turning on her axis, which greatly modifies this action, it will be necessary to advert to it. Writers

on rotatory motion state, and their statement is of easy proof,—that when a body revolves in free space, it turns on an axis passing through its centre of gravity: also,—that when a system of bodies is suspended on an axis, the *time* of a vibration is determined by the distance of the centre of oscillation from the axis, which centre is found by multiplying every particle by the square of its distance from the axis of suspension, and dividing the sum of all these products by the product of the whole quantity of matter multiplied by the distance of its centre of gravity from the same axis. Some writers on the rolling of ships, consider the first of these propositions applicable to their subject; but that they are in error, we may conclude from the reflection, that not only are the keel and sharp parts of the ship forward and abaft, but also the displacement of water on the immerged side, is so powerfully opposed to such a rotation, that it would be suddenly stopped. On the contrary, other writers, and Chapman among them, whose name alone is a host on subjects of naval science, consider the axis of rotation to pass through the metacentre, and that the second proposition, that for finding the centre of oscillation, strictly applies to a ship's rolling; in which opinion the Chevalier Barrallier, who was the first man in England who endeavoured to introduce scientific principles in the construction of ships, perfectly coincided. The latter view of the case will be best illustrated, perhaps, by taking into our consideration the rolling of a cylinder floating longitudinally on the water; now, as all the action of the water is perpendicular to the surface, the direction of its force is all to the centre of the cylinder; and when rolling takes place, the operation must be precisely the same as though the body was suspended at that centre; this point is evidently the metacentre.

To apply these principles to the practical diminution of the violent rolling of a ship, we should first ascertain the stability; if it is more than is necessary for keeping the ship sufficiently upright against the pressure of her sails, the most efficacious way of diminishing her rolling, is to wing up the ballast; because, in the first place, it raises the centre of gravity, which brings the ship nearer to the state of the Caledonia, shown in Fig. 13, and which ship is reported to roll quite easy; and, in the next place, it increases the distance of the centre of

oscillation from the axis of rotation; which it does in this manner: the ballast that is removed from near the keelson to the wings, even if placed as high as the deck, is as far from the metacentre as though it was in the hold; and consequently, its weight multiplied by the square of that distance, is the same as before; therefore, the sum of the products of every particle in the ship, multiplied by the square of their distance from the point of suspension, is the same as before; but this sum has to be divided by the weight of the ship, multiplied by the distance between the metacentre and the centre of gravity, which distance being diminished, the quotient, which is the distance of the centre of oscillation from the axis of suspension, is proportionately increased, consequently, the rolling from this cause also will be slower. If the same quantity of ballast was taken out of the ship, the first of these causes would operate precisely the same, the second would be less powerful; but at the same time it should be recollected, that lessening the weight of a ship, reduces the area of the immersed part of the midship section, and also in other ways renders the resistance less; and, therefore, as quick sailing is always an object of importance, the reduction of the quantity of ballast is generally to be preferred, even at the expense of a little less easy rolling. If the ship should have no surplus stability, the masts and yards must be reduced so as to give her such; and then she will be in the same case, as in the former supposition. Other means may be used, either with or without altering the position, or taking away a part of the ballast; the cables, shot, stores of various kinds, &c., may be placed nearer the side, which, without affecting the stability, would increase the distance between them and the axis of rotation, and consequently lengthen the time of a vibration.

It is by no means a difficult task to reduce a ship of extraordinary stability, which is always an uneasy one, to a state of easy rolling. There can be no doubt, but that had the 64-gun ships, which have been already alluded to, when they were cut down, had their masts and yards a little increased, instead of their being reduced to a 38-gun ship's masts and yards; and had half their ballast been taken out, and at the same time, had their guns been changed for others of a larger calibre, instead of some of them being of a smaller, they would have been easy,

would have sailed better than any class of ships then in the navy, and the expense of their wear and tear, would not have exceeded the ordinary amount.

Should it be thought proper, in order to improve the qualities of the brigs of ten guns, to form a new construction retaining their present tonnage, their breadth should be increased, and their length diminished in proportion; the increase of breadth would raise the metacentre, and allow the centre of gravity to be also raised nearly the same quantity, the centre of displacement should be kept as low down as the present brigs have it. These alterations, as regards their rolling, would give them a better proportion between the distance of the centre of gravity from the metacentre, and the distance of the centre of displacement from the metacentre. A less portion of ballast should be put in them, and guns of a larger calibre should be placed on their decks, this would raise the centre of gravity the requisite quantity, and at the same time, the centre of oscillation would be at a greater distance from the axis of rotation. As the stability would be greater, the masts and yards should be enlarged, which would enable them to overcome the additional resistance, arising from the small increase of the midship section. It may therefore be concluded, that the alterations suggested, would give them the advantage of easier rolling, with a superior armament.

ART. VI.—*Method of fitting the Riding Bitts of Ships without Cross-pieces; and a Method of fitting a Launch or Long-boat, to carry out or weigh a Bower Anchor.* *By* CAPTAIN *the Honourable* GEORGE ELLIOT, R.N.

(*To the Editors of Papers on Naval Architecture.*)

GENTLEMEN,

I SEND you an account of two of my late propositions, which as they apply to all descriptions of ships, you may think worthy of notice in your next number of 'Papers on Naval Architecture.'

I remain, Gentlemen,

Your very obedient servant,

GEO. ELLIOT.

H. M. Ship Victory, Dec. 7th, 1829.

Method of fitting the Riding Bitts of Ships without Cross-pieces.

The cross-pieces of the riding bitts of ships, which are much in the way, and an unnecessary weight on board ship, may be done away with, by the following method of fitting the bitts. The bitt-heads must be rounded, and as usual for chain cables, cased with iron; but the iron casing must be carried lower than when fitted with cross-pieces, and there must be a projection on the after side, to prevent the cable from rising. Fig. 19 represents a bitt-head so fitted; the part *abc*, shows the iron casing, *d* is a projection of the iron to prevent the cable from rising, *e* is an iron plate on the upper side of the standard, on which the cable runs; and *f* is a hole passing through the bitt-head, in which a handspike is placed to keep down the cable, when a hempen cable is used. A roller is used on the after bitts, to support the cable in heaving in. The cable leads from forward under the projection, round the bitt, and then passes over the projection aft.

The standard on the fore side of the bitt, keeps the cable up after the turn is taken; and as there is as much surface exposed to the friction of the cable on the whole circle, as on the half circles of the bitt-head and cross-piece in the old manner, equal security is afforded. The cable by this method is brought much lower on the bitt-head, which will therefore not work so much as with the cross-piece.

In new ships the bitts should have a sufficient rake aft, to give the cable an inclination to go downwards when a strain is brought on it.

It has been highly approved of in H.M. ships Briton, Galatea, and Undaunted, where it has been some time on trial. The weight removed from the Briton, by this mode of fitting her bitts, was nearly sixty hundred weight, exactly the weight of her two forecastle guns.

Method of fitting a Launch or Long-boat, to carry out or weigh a Bower Anchor.

It is only necessary to fit a windlass, about three feet longer than the extreme breadth of the boat, resting on the gunwales, with the projecting ends tapering outwards. One part of a

double buoy rope is brought to each end of the windlass in the usual way. Fig. 20 represents the transverse section of the boat, *a a* are the projecting ends of the windlass, to which the ends of the buoy rope are brought, which pass round the flukes of the anchor when suspended. The ends of the windlass rest on strong chocks fitted on the gunwales of the boat, which must be strongly framed and well secured to sustain the weight.

The advantages of this plan consist in the extreme simplicity, and the great ease, with which the anchor is placed on, or taken off the boat.

Let the anchor be hung to the windlass, over the ends of which put a pair of slings, *bb*, and lower the anchor about three feet under water, either from the cat-head or the bowsprit, as may be convenient. Then haul the boat in between the buoy rope under the windlass, and lower away, till the boat gets the weight; unhook the cat, and the boat is free. Thus the boat need not be above a minute under the bows, or in a situation where she is likely to receive any damage.

In a boat eight feet wide, I had four sets of holes for the handspikes (which were 6 feet long); thus admitting of eight being shipped at a time, four horizontally, and four perpendicularly. With a rope to the end of the upright bar, I found that we could heave up an anchor of forty-eight hundred weight with only two bars. The whelps of the projecting ends of the windlass were twelve inches in diameter at the largest part.

There would be no danger of upsetting the boat in case of one rope giving way, as by the force acting at one end of the windlass, the other end would immediately rise, and the windlass would then be turned off the boat; or, if the other end was surged, it would fly off the end of the windlass. I found that one or two fore and aft bars would answer the purpose of a paul, a man attending each to ship it, and letting the end rest on the thwarts.

If the anchor is to be carried out from the ship, it will hang better by both flukes, or by the stock, than with the buoy ropes made fast in one place. To let go the anchor, make a stopper fast to each buoy rope at the water's edge; take a turn round the windlass with the inner end of each stopper, and lash their ends together; surge the buoy ropes and take off their turns, and cut the lashing of the stoppers when required to be let go.

Art. VII.—*Notice of "A Treatise on Masting Ships, and Mast-making. By John Fincham, Superintendent of the School of Naval Architecture, in H. M. Dock-yard at Portsmouth."*

The author of this work published a few years ago a small treatise on mast-making for the use of the students in the School of Naval Architecture, whose education in the practical part of ship-building he has directed for many years. The usefulness of this little work was considerable, but it was found to be not sufficiently extensive; and the present work was undertaken to supply the deficiency.

Steel's treatise on mast-making, was for a long time the only work on the subject in this country, and deserved all the favour it received; but from the numerous improvements since its publication, a new work on this subject had become necessary. It may also be observed, that this work related only to the practice of mast-making, not giving the principles on which it depends.

The author of the present work treats on the subject under the following heads: general observations on masting ships; dimensions and proportions of masts and yards; the timber used for masts; its conversion; the practical operations in mast-making; and the furniture of masts and yards.

The subject is treated so far theoretically, as to show the true principles on which the masting of ships depends; but on the whole, this work is rather to be received as an account of the results of experience, than as a treatise dependent on theoretical investigation.

The correct masting of ships depends on giving the masts and yards such lengths, and on so disposing the masts, that the moment of the sails may be in such a proportion to the moment of the stability of the ship, that when sailing on a wind, the ship may not incline too far; that the height of the centre of effort of the sails may be so situated with respect to the direction of the resultant of the water when the ship is going free, that the ship may neither incline forward nor abaft; and that the centre of effort as to the length of the ship, may be so situ-

ated with respect to the direction of the resultant of the water when sailing close-hauled, that the ship may come readily to windward, and work well. The latter considerations are attended with great difficulties. Many valuable observations are made by the author, which evince considerable acquaintance with the subject.

Chapman has given a correct method[1] of determining the length of the masts and yards in proportion to the stability, for ships of the line, in which their relative proportions are determined according to experience; in which the ships are supposed not to incline more than seven degrees, when sailing close-hauled. Mr. Fincham gives a table showing the proportion between the moment of sails and the moment of stability, for different classes of ships, supposing the inclination of the ship to be ten degrees, which he first published in an article on the small class of frigates, in the first volume of 'Papers on Naval Architecture.'

In this table the moments of the sails and of the stability are calculated from the loadwater section, on the supposition, that the centre of gravity of the ship is in that plane. If these moments had been determined from the true situation of the centre of gravity of the ship, the moment of the sails would have been diminished, but in a less proportion than the moment of stability, so that the terms in the lowest column, which are found by dividing the moment of sails by the moment of stability, would be rather greater than are shown in this table.

Rules have been given for determining the lengths of the masts and yards of ships in relation to their stability; but the difficulty of using the formulæ, has prevented this correct method from being adopted by this author. We do not, however, consider, that the difficulty of the operation is by any means a sufficient excuse for neglecting it. There is no occasion for the calculation of the lengths of masts and yards of ships, to be ever left to the determination of merely practical men: tables could be made for all classes of ships, in which the lengths and diameters of all the masts and yards might be given in linear

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1 See page 26, of this number of 'Papers on Naval Architecture.'

dimensions, and not in proportion to the lengths and breadths of the ships.

Mr. Fincham, however, observes, in favour of the method at present used, "the common rule for determining the masts and yards by the length and breadth of the vessel, has been admitted by long use, and may be considered equally good with any of the rules at present given as approximations; for the yards must be governed by the length, in order that the sails may have a suitable spread; and the breadth, which determines the length of the masts, that they may have proper support by the spread of the rigging, has the greatest influence on the stability."

Agreeably to this method, the author has given a very valuable collection of tables, showing the lengths of the masts of all classes of vessels distinguished by their breadth, and the lengths of the yards of all classes of ships distinguished by their length, in feet and decimal parts of a foot. Tables of the diameters of all masts and yards are given in inches agreeably to their lengths.

Some general observations are offered on the position of the centre of effort of the sails, when a ship is sailing on a wind, which depends on the resultant of the direct and lateral resistance of the water on the ship's body, which the author observes, "will be seen by a reference to an example given in 'Chapman's Treatise on Ship-building,' chap. 10, not only to be attended with a considerable degree of uncertainty, from our imperfect knowledge of the action of fluids, and in fixing the proper angle of the lee-way; but to be attended also with considerable trouble, from the extent of the calculations required." Frequent references are made to the excellent observations of Lieut. Carlsund and Mr. Henwood, in several articles on this subject in 'Papers on Naval Architecture.'

On the proportion between the moments of sail forward and abaft, taken from the middle of the length of the water-line, the author has made similar remarks to those he published in Art. 47, vol. 1., on the elements of small frigates. He observes, "that the moment of sails forward in comparison to the moment of sails abaft, of several ships that were found to work well, according to the reports given by experienced officers on board them, varied from 1 : ,72 to 1 : ,77. It would appear, therefore, according to the experience we have from good ships, that the

relation of the moments should be somewhere between these two limits; and having determined this, which may be done with more certainty by examining the moments of a greater number of ships, any little disposition to come to, or fall off, may always be corrected by an attention to the trim, and that without affecting any other quality of the ship." A table is given, showing the relation between these moments for all classes of ships; in which are also shown the situation of the centre of effort of the sails, and other elements.

In this table the area of the sails is given in proportion to the area of the loadwater section; Forfait, in his Treatise on Mast-making, gives the area of sails in proportion to the parallelogram circumscribing the loadwater section. The former, certainly shows the area of the sails in connexion in a small degree with the form of the ship; but the latter gives it more in conformity with the method followed by both authors in determining the lengths of the masts and yards in relation to the extreme breadths and lengths of the ships. Neither of these proportions, however, shows the relation between the moments of sails and moments of stability. By this method of determining the lengths of the masts and yards, the moment of sails is in proportion to the length and the square of the breadth, or as the third power of the simple dimensions of the ship, whereas the moment of the sails ought to be determined in relation to the stability, which is proportional to the length and cube of the breadth, or the fourth power of the simple dimensions of the ship.

There is one element to which the author alludes in his general observations, as very considerably affecting the resultant of the water, which we believe he has been the first to notice: the situation of the centre of gravity of the vertical and longitudinal section of the ship. This element was calculated and published in an article on the dimensions and elements of small frigates, by this author, in vol. I. of 'Papers on Naval Architecture.' Its importance is not, however, established by any reasoning: in fact, we conceive that the only advantage which can be attributed to this element above the trim of the vessel, is, that it includes the difference of rakes of the stem and stern-post, which the trim does not show. We do not consider that

the trouble of the calculation is compensated by its utility, and that generally the draughts of water forward and abaft will be found to be better adapted for comparison: probably, the author afterwards did not consider it of so much importance, otherwise, we conceive, he would not have omitted it in the tables of elements he has given in reference to the areas of sails.

Instead of determining the main-mast immediately in proportion to the breadth of the ship, and the main-yard in proportion to the length, Mr. Fincham first determines the surface of the sails and their proper position, and thence determines the lengths of the masts and yards. Examples are given of the proportions of the courses, top-sails, and top-gallant-sails, of all classes of ships, taking the height of the head of the top-gallant-sail as a constant quantity in each class, under three heads, deep courses, deep top-sails, and deep top-gallant-sails.

Mr. Fincham observes, "in fixing the proportions of different sails to each other, as the depth of top-sails to that of the courses, of top-gallant-sails to top-sails, the depth of the top-gallant-sails to that of the courses, or the proportions of the sails on the fore and mizen-masts to those on the main-mast, we shall be guided best by our observations as to the proportions that have been given to different ships,' without any disadvantageous consequence in their application; for in every case in which the proportion of different sails to each other has been carried to the extreme either way, experience has soon discovered the error, and determined the limits: thus, making the sails too nearly equal on the main and fore-masts, cannot be done without pressing the ship too much forward, or by carrying the fore-mast back; which not only obstructs the proper working of the yards, but prevents the wind having its full effect on all the sails. If the top-sails are too deep in relation to the courses, there is a difficulty in shifting a top-mast; if the top-gallant-sails are too square, it is difficult to support the superincumbent masts, or if too narrow, the proper area of sail cannot be obtained without making the sail too taunt, or increasing the moment in a greater proportion to the area, than is necessary to bring the centre of effort to its proper height."

Many excellent observations are given on the dimensions and proportions of sails: we will quote those on obtaining the depth

of the course. Mr. Fincham observes, "to determine the length of the lower-masts, it will be necessary, first to get the true position of the head of the course in relation to the stops. To obtain the depth of the course, the sail-maker takes from the hounded length of the mast, what the mast is housed to the uppermost deck, the height of the foot of the sail above the deck, and what the yard is below the hound, for which he in general takes ⅔ the length of the mast-head. This rule, however, for placing the yard is different from that commonly observed by seamen, as they in general take half the length of the cross-tree, and set it down from the lower side of the opposite trestle-tree; which rule, if applied to a 46-gun frigate, would place the yard 4 feet higher than the position that would be taken for cutting the sails, and in consequence, make the top-sails too deep, which is frequently found to be the case; and should the yards be placed according to the sail-maker's rule, with the disposition of the fixed blocks, while the tacks and sheets are worked on the quarter-deck, forecastle, and waist, it would be impossible for the main-sail to stand without more height above the deck, than with the proper roach." He proceeds to observe, that it would be more consistent to determine the length of the mast-head and place of the cat-harpins in terms of the top-mast, for which he gives proportions.

Mr. Fincham gives numerous tables of the lengths of the masts and yards for all classes of vessels, beginning with boats. Tables of the dimensions and areas of the sails are given for boats of different rigs, but are not continued for ships. The author was no doubt deterred from giving the detail of the sails of ships, by the great trouble the calculations would have taken: he has, however, done so much, and given us such a very valuable collection of tables, that we have no right to complain he has not done more; we merely mention it as an imperfection in the work, and consider that as he has not given us similar tables for ships, those for boats might as well have been omitted, particularly as it appears to give an undue consideration to the areas of the sails of boats, a subject which is certainly of comparatively inconsiderable importance.

By having the establishments of masts and yards as few as possible, considerable advantage is obtained in the ready supply

of ships which require to be hastily masted; this convenience is, however, attended with the disadvantage of ships of different dimensions and various qualities having the same masts and yards, by which some must be over-masted, and others under-masted. When a ship is designed, its qualities are determined in connexion with the moment of its sails, and if the masts and yards are not determined in correct relation to it, the excellency of its qualities cannot be known. The diminution of the classes of the ships of the Royal Navy, as far as different services admit, will be attended with great advantage: in fact, the qualities of our ships will never evince that excellency, which we know that many of them possess, till the masting and equipment of every ship, are determined in strict relation to its design.

It is observed, on the diameters of masts and yards, "in determining what strength and form should be given to the different spars, of which the masting of vessels consists, so that a due support may be afforded for resisting the efforts that tend to break or upset them, we must be guided by our observations on the effects produced on the different descriptions of spars, and by what experience and long usage have determined to be the best, rather than by any abstract theory. The difficulty of obtaining correct data respecting the stresses that masts, yards, &c., are subject to, in every situation, and at the same time including the different supports that they receive under all circumstances, renders any analytical reasoning of little use; and though the conclusions that Bouguer and other writers have formed are ingenious, and founded on the strictest reasoning, yet, on account of their having neglected to take into consideration some particular stress, action, or support, they have been found to be of little use in practice. The diameter and form, as at present established, appear to have been determined from the experience of the mast-maker; who, in order to lessen the expense, and diminish the weight, might at first have been induced to give the masts, yards, &c., very small diameters; but afterwards, according as he may have found them weak, wrung, twisted, or ruptured, has continued to increase their diameters, and consequently their strength, till they are become of that form and size which he considers to be best.

It is from a knowledge of the limits which experience has marked out, that we are able to form such a judgment respecting the strength and diameters that are necessary for all masts, yards, &c., as cannot be far from being correct."

Tables are given of the diameters of all masts and yards in relation to their length, in which the diameters of the smaller lower masts are increased in respect to those commonly used in H. M. dock-yards. Experience led to an increase of these diameters above twenty years ago, and it appears still to justify further increase.

A comparison between the diameters of the main-masts of different classes, and the strains they sustain, is given by the author in a note. "The moments of pressure on the main-mast, above the upper wedging-deck, is, for three-deck ships, 573073; two-deck ships, 493060; frigates, 425194; and corvettes, 199657; where the diameters would be, for three-deck ships, 41 inches; two-deck ships, 36 inches; frigates, 31 inches; and corvettes, 21 inches. If, therefore, we were to consider the strength of masts to vary as the cubes of their diameters, which, in practice, would not be far from the truth, the proper diameter, in proportion to the stresses when brought in relation to the three-deck ships, would be

[1] $573073 : 493060 :: 41^3 : \text{diam.}^3$ diam. $= 39$ inches for two-deck ships.

$573073 : 425194 :: 41^3 : \text{diam.}^3$ diam. $= 37$ for frigates.

$573073 : 199657 :: 41^3 : \text{diam.}^3$ diam. $= 28$ do. corvettes.

This shows that the excess of strength is very considerably in favour of the three-deck ship, which accords with experience, since the proportion of three-deck ships' masts that are sprung, is very inconsiderable, when compared with ships of other classes; however, the difference of diameters will not be so great as the proportions give, since considerable allowance must be made for the excess of weight, as well as pressure, that the larger masts have to sustain."

Different proportions are also given in many instances for the small diameters of the different spars from those used at

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[1] These proportions are incorrectly stated by the author, who probably intended to have stated them as above, as his results are correct.

present: from the heads of masts being frequently found to be wrung, particularly of frigates and smaller vessels, the diameters are increased. The proportions of the outer ends of bowsprits are also increased, in consequence of their being found to be sprung oftener between the gammoning and cap than elsewhere.

We must however observe, with respect to these alterations, that we conceive, in a work professedly written on the practice of mast-making in this country, it would have been more proper to have given the proportions which are at present commonly used, in the body of the work, and the alterations, however just, which the author suggests, in the notes; instead of giving his new proportions as the standard, and the usual proportions in the notes.

The author gives some useful remarks on the different kinds of timber used in mast-making, with the results of some experiments he made on their strength and elasticity; observations are also given on the receipt and preservation of mast timber. The method of converting mast timber is also given, with the sizes of the sticks required for different masts and yards.

The work concludes with an explanation of the practical operations of mast-making. The new made-mast of Sir Robert Seppings, being now generally adopted in his Majesty's dockyards, for ships of the line and frigates, properly forms a principal part of this division of the subject. The object of this method is the substitution of Riga timber in the large masts and bowsprits for white and yellow pine; by which they are not only made of stronger and more durable timber, but their expense is considerably diminished. These masts also possess the advantage of being conveniently removed from one port to another, and of being easily repaired. We shall give the detail of putting together these masts from this work, and afterwards give accounts of the patent made-masts of Messrs. Ferguson and Hillman,[1] and of the made-masts long used in Holland, with the alterations proposed in them by M. Rolland, a French naval engineer.

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[1] An account of Mr. Green's patent made-mast is also given at page 106, in this Number of 'Papers on Naval Architecture.'

The account of putting together the masts of Sir Robert Seppings, was evidently drawn up by the author previously to the adoption of the present method, as a description is given of fastening these masts with bolts; and a paragraph, afterwards added, showing the substitution of treenails. We shall therefore give such parts of the description as agree best with the present mode. It may be observed, that several inaccuracies appear in this part of Mr. Fincham's work in the references to the figures, no doubt arising from the author's endeavouring to make the description conform to the present mode by additions, instead of re-writing the whole of the description.

"The new made-mast is composed of a number of square pieces, each side being one-fourth the diameter of the mast, for ships of 60 guns and upwards; and one-third the diameter for smaller ships. These pieces are in length according to the length of the mast, and are placed end to end, with their butts under the hoops. Four of these pieces, in a sufficient number of lengths to make up the length of the mast, are first united together to make the main piece, or what is called the core; on each of the four sides of which two pieces are united together, and brought upon it to make up the diameter. The pair on each side, and the after pair, extend the whole length of the mast; but the pair on the fore side is short once and a half the depth of the trestle-trees less than the length of the head of the mast from each end.

"These masts are formed to have both ends alike, to afford an opportunity, in case of defect or injury, of placing either end uppermost; each end is therefore made to form the head, and of a length the same as the common mast-head.

"The exterior form of the body of these masts is cylindrical; the parts at each end, to the length of the common mast-head, are formed with the angles only taken off, the same as the common heads.

"*New Made-masts for Ships of the Line.*—The several pieces that make the masts are placed with their butts under the hoops. To determine the length of the pieces and the place of the butts for 60-gun ships and upwards, divide the length of the fore-fish into fourteen equal parts, to give the stations of every other hoop, with one placed at the middle of

the mast; which will likewise give the station where one butt and its opposite, on opposite quarters, will be placed; six of these spaces will give the lengths of the middle pieces, while the pieces that run through at the ends, may be longer or shorter as can be obtained.

"The first butt in the fore and after pair is placed under the middle hoop in one piece, and the opposite on the opposite quarter; and in the other two pieces in this pair at three spaces on each side of the middle, so as to bring the butts to the middle of each piece. To the two side pairs, one butt and its opposite, on the opposite quarter, are placed one space from the middle, while the butt of the other piece is placed at two spaces on the other side of the middle.

"The main assemblage or core has the butts the same, in relation to the middle hoop, as the side pairs; that is, the butts at the corresponding spaces on the opposite side of the middle of the mast lengthways.

"When the first butts from the middle are determined, the others will run regularly from them, except those lengths that run through at each end. The pieces are trimmed and planed up to their dimensions; the core is then put together. To bring the pieces that make up the different lengths in a direct line, a sufficient number of blocks or skids, to take the length of the mast, are placed in the same plane, at distances from each other, so as to take the butts. The different pieces have their butts made square, and brought together according to their shift; and when in a direct line upon the skids, the butts are coaked with one coak in each, three inches in diameter and six inches in length. To bring the butts, in the several lengths in the four parts that make the core, into close contact at their abutments, a force is brought upon the ends, at the extremities of the mast, by means of a set by wedges at each end, against some part of the mast-house, or any place where sufficient support can be obtained; and that the four parts may be closely united, sets to wrain-staves are made to each skid one way, and brought together by clamps the other way. When the pieces that form the core are brought together, they are united by treenails, about two feet apart, commencing six inches from the butts, driven from one angle to the opposite, with those in

the opposite diagonal placed at the same distances, but to pass in the middle between them.

"To make up the deficiency that is left by the breadth of the pairs to give the form of the mast, aris pieces, or ekings, *a*, Fig. 21, are brought into the spaces between the edges. These pieces have their butts placed under the hoops, so as to give shift to the butts of the pairs, or to correspond with the butts of the core; they are fastened with mixed metal screws, eight inches long, between every two hoops, and one a foot from each butt.

"The hoops on the body are spaced as described in shifting the butts; that is, a hoop over, and one between, every two successive butts, with one about three inches from each end of the foremost pair, and one at the hounds. The head-hoops are spaced with one against the end of the foremost pair, or once and a half the depth of the trestle-trees above the hounds; one three inches below the tenon of the cap, and four at equal distances between.

"The body-hoops are screw-hoops in two equal parts, with the ears for the screw on each side of the mast. To cover the ears and screw, so as to prevent ropes from catching, a piece of fir, six inches thick, and nine inches wide, is brought upon the side of the mast, and let over them.

"The masts that have lately been formed on this plan, have been fastened with treenails. The pieces that form the core are united by treenails, two feet apart, and commencing at six inches from each butt, Fig. 22 and 23, *d, n*. When the core is together, the side pairs are brought against it in their proper position, and the treenails driven; those in the edges, Fig. 23, 24, and 25, *e*, that unite the pieces into pairs first; and then those that combine them with the core, *a a*. The treenails in the edges, that unite the pieces into pairs, are placed opposite the middle of the distance between the treenails and the core, in every alternate space; and the treenails that unite the side pairs to the core, in the intermediate spaces, one in each piece of the pair, to pass through both pairs and the core. The treenails in the fore and after pairs are placed, those through the edges opposite to those that unite the side pairs to the core; and those that unite the fore and after pair to the

core, Fig. 25, *c*, opposite to those in the edges of the side pair. This gives the treenails at the spaces of about every six inches; those in one diagonal of the core, Fig. 23, *d;* those in the edges of the side pairs, *e;* and those that pass through the fore and aft pair and core, Fig. 25, *c;* those in the opposite diagonal of the core, Fig. 23, *n;* and then those on the edges of the fore and after pair, and those that unite the side pair to the core, Fig. 25, *a*. The treenails, except those in the core, are always placed in the middle of the pieces, in relation to the edges, and are of a size; those in the core, 1½ inch; in the side and fore and after pairs, 1⅜ inch; and those in the edges, 1¼ inch. In the heads, in addition to the treenails, there are six ⅞ bolts[1] that pass through the side pairs and core, and fore and after pairs and core, between the hoops.

"*Frigates' new Made-mast.*—The masts of frigates, after the length of the head is taken out from each end, the remainder, or body of the mast, is divided into eighteen equal parts, giving nineteen stations for the place of the hoops and butts. To give the butts their proper shift, the first butt is placed for the after fish, at the middle station; for the core, at the station six spaces above the middle; for the fore fish, four spaces; for one side fish, two spaces above, and for the other side fish two spaces below the middle; and then from every butt ten spaces or parts are set off for the length of each piece, and for the places of the other butts, which will place them, for the core and fishes, two spaces apart. For the butts of the aris pieces the starboard after one has the first butt one space above the middle; starboard fore, three; larboard aft, five; and larboard fore, seven spaces above the middle station; when from these ten spaces are set off, the same as for the fishes and core, for the other butts. The butts thus placed give the proper disposition in relation to each other, with a distance apart of about 3 feet 6½ inches, for a 46-gun ship's main-mast; and will give the whole length of the pieces, those at the middle, about 35 feet 6 inches, and the others varying from 16 to 44 feet, except the fore fish will always be half of the length of the mast, both heads included.

[1] In consequence of the reduction of the scantling of the side and after pairs, ⅞ bolts are substituted for treenails; but no bolts pass through the core.

"In applying the fastening to these masts, the core and fore and after fishes are first brought together. The after fish is laid straight on the skids, and then the core and fore fish are brought on it; when to each abutment is placed one circular coak, five inches in diameter and three feet in length. When the abutments are set close, these pieces are treenailed together; one treenail is placed twelve inches on each side of each butt, which passes through the coak, and others at every two feet apart, or as near as they will space, Fig. 26 and 27, *c*. The side fishes are next brought on and coaked at their abutments as the fore and after fish and core, and fastened with one treenail, which passes through, in the middle between the other fastenings, Fig. 26 and 27, *a*. The aris pieces are coaked at their abutments with one circular coak, three inches in diameter and six inches long, and are fastened with treenails, which pass through from one aris piece to its opposite on the opposite quarter of the mast, and are spaced at the same distances apart as the other fastenings, with one in the middle between each of those that compose the fastenings of the side and fore and after fishes, Fig. 26 and 28, *e*. The whole of the treenails in frigates' masts are 1¼ inch in diameter.

"Frigates' masts are formed cylindrical all through; but at once the depth of the trestle-trees, above the place of the hounds, at the fore side, on one of the arisses of the mast, an abutment is sunk in 4½ inches, and the mast taken through straight, from which it is gradually formed for the mast to be cylindrical at the head.

"The body hoops are placed at the stations of the butts, and screw up, as explained for ships of the line; and the mast-head hoops are placed, one 3 inches below the tenon, and one 1½ the depth of the trestle-trees above the hounds, and four others at equal distances between."

The patent made-mast of Mr. Ferguson has a similarity to that of Sir Robert Seppings, just described. It is formed of a core, either square or polygonal, with side-pieces round it, making up the cylindrical form of the mast. The ends of the pieces forming the core are cut off perpendicularly to their length, and are connected together at their ends by three or more screw-bolts, of from ¾ to 1½ inch in thickness, entering

about three feet into each piece, having a screw at each end, the one a right-hand screw, and the other a left-hand screw; mortices are cut in these pieces to admit nuts being screwed on the ends of the bolts, with washers between them and the wood. These mortices, which are so placed as not to be in the same transverse section of the mast, are afterwards filled with hard pieces of wood. Metal plates are introduced between the butts. The ends of the external pieces are connected together in the same manner; and all the butts are so disposed as co give shift to each other.

The pieces which form the mast are coaked together, and cross-bolts are driven through three adjacent pieces; not passing through the centre. They are so disposed, that the ends of two may come near each other in the same piece. The mast is then secured by drift-hoops where practicable, elsewhere by clasp-hoops.

Another method is also given by Mr. Ferguson for disposing the long screw-bolts, which connect the ends of the pieces: instead of driving these bolts into holes, bored in the ends of the pieces, they may be placed in grooves cut in the sides of the pieces, the external sides excepted, and screwed up as before.

The patent made-mast of Mr. Hillman is composed of a core, with external pieces, from three to nine in number, to make up the mast. The peculiarity of this mast consists in the pieces being connected to each other laterally, by long dove-tailed battens driven into grooves taken out of the sides of the pieces; see Fig. 29, which represents a transverse section of this mast. These battens and grooves taper a little upwards, for the sake of being driven tight. The ends of the pieces which form the mast are scarphed together, and have doubly dove-tailed battens let into the scarphs. The lips of the scarphs are cut off obliquely to tail into the thick parts of the scarphs.

When the pieces are trimmed and brought together, the masts are lashed firmly together by ropes, or secured by hoops, and the dove-tailed battens are then driven into the grooves. The temporary security is then removed, and the masts are secured by iron hoops, in the usual manner. These masts are wholly put together without either coaks or treenails.

Mr. Hillman gives also a method of working the dove-tail

in the solid wood on the side of the piece, which fits into a corresponding groove taken out of the adjacent piece.

The following account of the made-masts used in Holland, is taken from M. Forfait's 'Treatise on Mast-making.'

The whole length of the main-mast of the Evertsen, a ship of 80 guns, was $104\frac{1}{2}$ French feet, its greatest diameter was 34 inches, and the length of the head 14 feet.

The head was formed by the upper part of the spindle, and was octagonal; its size was such that the diameter of the circle, circumscribed by the octagon at the hounds, was $26\frac{1}{2}$ inches; and a similar dimension at the upper part of the head was $22\frac{2}{3}$ inches. A stop of an inch and a half in depth was formed at the hounds on each surface of the octagon, by which the size of the spindle immediately below the hounds was reduced, so that the diameter of the circle, circumscribed by the octagon, was only $23\frac{1}{2}$ inches; the spindle was then worked throughout its length to an octagonal shape, and tapering towards the keel; where its size was determined, according to the practice in the mast-houses of Holland, by the rule, that the diameter of the circle circumscribed by the octagon of the lower extremity of the spindle, shall be at least equal to one half the diameter of that circumscribed by the octagon of the upper part of the head; consequently in this mast it was $13\frac{1}{4}$ inches. But if the rough mast, out of which the spindle is formed, will admit of a greater proportionate size for the lower end of the spindle, it is rather considered advantageous than disadvantageous.

If a stick, of sufficient length to form the spindle, cannot be procured, as is generally the case with large masts, the lower part is formed by a lengthening piece, which is united to the upper or principal piece by a long scarph: this scarph, in the mast of the Evertsen, was 20 feet in length, and was secured by five hoops; it had also five or six treenails in it.

When the spindle is completed it is painted with whitelead; and as soon as the paint is thoroughly dry, planks are worked on each of the surfaces, formed by the octagonal shape of the spindle, and secured to them by nails. These planks do not run higher than the hounds, where there is a stop to receive their ends. If the planks are not long enough to

extend the whole length from the hounds to the heel, unless by a sacrifice of timber, too valuable to be applied to such purposes, lengthening pieces are added at their lower ends, but never to extend higher than the partners of the lower deck; and care is taken to shift the butts, so that they may not all be at the same height. When the mast is thus far completed it is rounded, and the seams are caulked and then pitched over. The mast is then hooped, with drift-hoops, from the heel to the partners of the quarter-deck, and from thence to the hounds, with clasp hoops. The head is hooped with drift hoops; the hoops are spaced at four feet between their centres.

M. Rolland proposes that this system of making masts shall be introduced into the French dock-yards, with modifications, which he considers would remove all objections to it. He says that the using nails to connect the planks with the spindle is extremely injurious; that they do not prevent the planks from working, but tear the fibre of the wood, and consequently weaken its strength; besides which, they render repairs expensive; as when a mast is taken to pieces for that purpose, many pieces, which would otherwise have been saved, are condemned in consequence of the injury they have sustained from the nails.

He therefore proposes that the system of spindle and planking should remain as in the Dutch masts; but instead of bringing the planks and the spindle together with flat surfaces, and nailing them, that mortices, of 1 foot in length, 1½ inch in breadth, and 2 inches in depth, shall be sunk on each surface of the spindle at a distance of 8 feet apart; and so placed, that the mortices on the several surfaces shall form a spiral line round the spindle, as shown in Fig. 30; into these mortices coaks of hard dry oak are to be driven, which are to project as much above the surface of the spindle as they are sunk within it; similar mortices are then to be taken out of the planks to receive these projecting parts of the coaks, the abutments of which will prevent any working, and render the use of nails unnecessary. M. Rolland recommends that the seams should be caulked, and that the masts should be hooped with drift hoops throughout, at three feet apart.

Art. VIII.—*A List of the Patents which have been taken out since the First of January,* 1829, *for Inventions or Improvements connected with Naval Affairs; with Copies of Specifications, &c.*

As our object is to collect in the pages of this work "all the information that can be obtained on Naval Architecture, and other subjects connected with Naval Science," we intend in our future numbers, to publish lists of all the Patents which may be taken out for all improvements or inventions which relate to Naval affairs, with either the whole or parts of the specifications of those, which appear particularly connected with the design of this work.

List of Patents.

To Orlando Harris Williams, of North Nibley, in the county of Gloucester, esq., for certain improvements in the paddles and machinery for propelling ships, and other vessels, on water. Dated January 7th, 1829.

To Septimus Gritton, of Pentonville, in the county of Middlesex, surgeon, and late of the Royal Navy, for an improved method of constructing paddles, to facilitate their motion through the water. Dated January 7th, 1829.

To Francis Neale, of the city of Gloucester, barrister at law, for a machine, apparatus, or combination of machinery, for propelling vessels. Dated January 7th, 1829.

To Archibald Robertson, of Liverpool, in the county of Lancaster, ship carver, for certain improvements in the construction of paddles, for propelling ships, boats, or vessels, on water. Dated January 7th, 1829.

To William Erskine Cockrane, of Regent-street, in the county of Middlesex, for an improvement in, or on, paddle wheels, for propelling boats, and other vessels. Dated January 14th, 1829.

To Julius Pumphrey, of Tally Hill, in the county of Worcester, glover, for certain improvements in steam-engines, and machinery connected therewith, to propel steam-boats, and

other vessels. Some parts of which improvements are applicable to other purposes. Dated February 3d, 1829.

To Richard Green, of Blackwall, in the county of Middlesex, ship-builder, for certain improvements in the construction of made-masts. Dated February 5th, 1829.

To William Prior, of Albany-road, Camberwell, in the county of Surrey, gentleman, for certain improvements in the construction and combination of machinery for securing, supporting, and striking, the top-masts and top-gallant-masts of ships and other vessels. Dated April 11th, 1829.

To John Lihou, of Guernsey, but now residing at the Naval Club House, Bond-street, in the county of Middlesex, a commander in the Royal Navy, for an improved method of constructing ships' pintles, for hanging the rudder. Dated April 14th, 1829.

To Peter Pickering, native of Frodsham, Cheshire, and now domiciliated in Dantzic, Prussia, and William Pickering, of Liverpool, in the county of Lancaster, merchants, for an engine, or machinery, to be worked by means of fluids, gases, or air, on shore or at sea, and which they intend to denominate Pickering's engine. Dated 28th April, 1829.

To James Dutton, jun. of Wotton-under-Edge, in the county of Gloucester, clothier, for certain improvements in propelling ships, boats, and other vessels, or floating bodies, by steam, or other powers. Dated May 19th, 1829.

To Thomas Robinson Williams, of Norfolk-street, Strand, in the county of Middlesex, esq., for improvements in the making or manufacturing of felt, or a substance in the nature thereof, applicable to covering the bottoms of vessels, and other purposes. Dated May 23rd, 1829.

To William Poole, of the parish of St. Michael on the Mount, in the city of London, smith, for certain improvements in machinery for propelling vessels, and giving motion to mills and other machinery. Dated May 26th, 1829.

To William Mann, of Effra-road, Brixton, in the parish of Lambeth, in the county of Surrey, gent., for the application of compressed air, to communicate power and motion to fixed machinery, and to carriages, and other locomotive machines, and to ships, vessels, and other floating bodies. Dated June 1st, 1829.

To Elijah Galloway, of King-street, in the borough of Southwark, for certain improvements in steam-engines, and in machinery for propelling vessels, which improvements are applicable to other purposes. Dated July 2d, 1829.

To Jacob Perkins, of Fleet-street, in the city of London, engineer, for certain improvements in machinery for propelling steam-vessels. Dated July 2d, 1829.

To Robert Crabtree, of Halesworth, in the county of Suffolk, gent., for a machine, or apparatus, for propelling carriages, vessels, and locomotive bodies. Dated July 4th, 1829.

To George Straker, of South Shields, in the county of Durham, ship-builder, for an improvement in ships' windlasses. Dated July 25th, 1829.

To William Rodger, of Norfolk-street, Strand, in the county Middlesex, a lieutenant in the Royal Navy, for certain improvements in the construction of anchors. Dated August 21st, 1829.

To John Tucker, of Hammersmith, in the county of Middlesex, brewer, for certain improvements in the construction of cannon. Dated September 9th, 1829.

To George Harris, of Brompton-crescent, in the county of Middlesex, a captain in the Royal Navy, for improvements in the manufacture of ropes and cordage, canvas, and other fabrics or articles, from substances hitherto unused for that purpose. Dated September 15th, 1829.

To John Moore, of Broad Wier, in the city of Bristol, gent., for certain new or improved machinery for propelling carriages, also for propelling ships, vessels, or other floating bodies, and for guiding propelling carriages, and apparatus for conducting the steam of the steam-engine, after it has propelled the steam-engine piston. Dated September 30th, 1829.

To William Rodger, of Norfolk-street, Strand, in the county of Middlesex, a lieutenant in the Royal Navy, for certain improvements in the construction of cat-head stoppers. Dated September 30th, 1829.

To William Church, of Haywood House, near Birmingham, in the county of Warwick, esq., for certain improvements in machines for propelling vessels, and other machines capable of being propelled by steam, and in boilers applicable to the same, and also to other purposes. Dated October 15th, 1829.

To John Tucker, of Hammersmith, in the county of Middlesex, brewer, for an exploding shot or projectile. Dated November 2d, 1829.

To John William Dodgson, of Lower Shadwell, in the county of Middlesex, pump and engine maker, for certain improvements in ships' scuppers, and which may be applied to other purposes. Dated November 17th, 1829.

Extracts from Specifications, and Remarks.

Specification of Mr. Richard Green's Improvements in the construction of Made-masts and Bowsprits.—I the said Richard Green, do hereby describe the manner in which my said invention is to be performed, by the following description thereof, reference being had to the drawings hereunto annexed, and to the figures and letters marked thereon; that is to say, Figure 31, represents my invention as applied to joining the *butts* of two pieces, A, B, of square baulk timber, such as is used in forming the larger sized made-masts, *e* is a square tenon, formed on the piece B, of the length of 6 or 8 inches, and 4 inches square, and fitting into a corresponding mortice cut in the end of the piece A; *r r*, *s s*, is a wrought iron brace let into the pieces A, B, so as to be flush with their surfaces; there is a corresponding wrought-iron brace at the opposite side of the pieces A, B, and the two braces are bolted through the timber to each other. It will be observed, that the brace is wider at the two ends *r*, *r*, than it is in the middle, thus forming a double dove-tail, the ends *r*, *r* are also thicker than the rest of the brace, forming a shoulder on the under side, and consequently, let deeper into the wood. Figure 32 is a side elevation of the said brace, drawn to a larger scale, in order to show more clearly the increased thickness of the ends *r*, *r*. Figure 33 is a plan of the said brace; and it will be observed, that the width of the metal is increased at every bolt hole, and at the joining of the butts. Figure 34 is a transverse section of Figure 31. The butts of the pieces of square timber are thus secured, first taking care to pay their ends with coal tar, or any such mixture, and introducing a piece of canvas between the two, well soaked in the same composition. The core, or spindle of this mast, is to be made of 1 or 4 *square* pieces, according to the diameter of the mast, and the several pieces to

be connected round it with dowels or coaks, being introduced between all the surfaces 4 feet apart, 3 inches in diameter, and to go $1\frac{1}{2}$ inches into each piece; a bolt of 1 inch in diameter, to be driven through all the pieces at every other dowel in each surface, thus preventing the dowels from canting, and the mast from twisting in the bracing up of the yards, &c. The mast is then rounded and tapered from the heel and head, and hoops are drifted on, taking care that each butt shall be covered with a hoop; where drift hoops cannot be used, clasp or wedge hoops should be substituted. It will be understood, that no two butts or joints must lie in the same transverse section, they must be so shifted as to have a hoop between each. Figure 35 is a transverse section of a mast composed of four three-sided pieces of timber, the section is supposed to be made just at the butt of the piece; D and *e represent* the square mortice to receive a square tenon before mentioned; it will be evident, that when the pieces of timber of this shape are used to form the mast, the two braces which must in this case be placed as shown in Figure 35, cannot be bolted through to each other, and wood or coach-screws (as they are termed), therefore, only must be used in their places, as shown by the dotted lines. Figure 36 is a perspective view of the piece D, united after the manner of my invention to the piece F. The upper end of the piece D, is prepared to receive other similar braces, and G is a square tenon as before alluded to. It will be seen by this figure, that the three-sided pieces are connected together by dowels or coaks, three feet apart, three inches in diameter, and go $1\frac{1}{2}$ inch into each piece; and may be bolted together, if necessary, and hooped with drift or clasp hoops as in the larger masts, taking care to cover the butts with a hoop as before stated, which butts should be about 10 feet apart, thus having three hoops between each.

Observations communicated by the Patentee.—The object which this patent has in view, with the rest of the similar patents already granted, is the application of Riga or Dantzic timber for the construction of ships' masts; but particular attention should be directed to the security of the butts in the present instance, as there is no limit to the length or substance of the dove-tail braces which may be employed. Upon this

principle, therefore, it is assumed that the butts can be made so strong that if a strain be applied, the timber itself will give way and break before the butt will separate. The simplicity of workmanship is a point in favour of the construction of these masts, as well as the connection of the surfaces together with dowels and bolts; and, finally, the economy in the conversion of the timber, and the comparative small expense of labour. A circumstance has lately occurred which may, in some measure, illustrate the benefits to be accrued from this adoption. The East India ship, the Carn Brea Castle, which was wrecked at the back of the Isle of Wight, in July last, had her mainmast (which was 24 inches in diameter) made in four pieces, upon this principle. Upon her first getting on shore, it was deemed necessary to cut this mast away to ease the ship; it was cut half way through with an axe, the rigging which supported it being cast off; and although the ship rolled heavily at the time, the mast did not in any degree give way until cut through two-thirds of its diameter; it then began to rock, but did not go by the board for several minutes, notwithstanding that the top-masts were fidded, and the yards across, which caused a great weight aloft hanging entirely upon the mast. On the next day the fore-mast, which was a single stick of the same diameter, was cut a very few inches into the wood, and immediately after the rigging was cast off it went by the board.

Specification of Commander John Lihou's improved Method of constructing Ships' Pintles.—The above-named improved pintles are constructed of the same metal as is used at present for ships' pintles, or of any metal, or combination of metals, proper for the purpose. They are of two kinds, which may be distinguished from each other by the appellations of live or hanging pintles, and dumb, or bearing, or friction pintles; and they differ from those heretofore used, by being so formed and constructed as to admit of much greater facility of repairs; because each pintle is composed of separate parts, as hereinafter described. In my improved pintles, the pin, or pivot, of the hanging pintle, and the bearing stud of the bearing, or friction pintle, are made separate and detached from the remainder of the pintle, and can be taken out and put in again

at pleasure; consequently, if the pin, or pivot, or bearing stud, should become damaged or broken, it may be taken out and renewed without re-constructing the side brace or strap. The common, or ordinary googings, are to be used in conjunction with my said improved hanging pintles to keep the rudder to the stern-post.

The improved hanging pintles consist of the usual side braces or straps, furnished with bolt-holes for fastening or securing it to the rudder, and the head, or boss, or mass of metal, from whence its pin or pivot projects; but instead of the pin or pivot of the pintle being cast, forged, or formed in one piece, with such head, boss, or mass of metal, a hole must be made through the boss to receive the pin or pivot; which hole may be cylindrical, oval, square, polygonal, or slightly conical, or tapered.

Whatever shape it may be formed of, the head, or upper part of the pin or pivot, must be formed of a corresponding shape, and be made to fit it tightly, and without shake, the intention being that the pin or pivot may be firmly fixed, and rendered incapable of turning round in the boss, or of falling through it. To ensure this the more effectually, the head, or upper end of the pin or pivot, may be formed with a feather, or with fins upon it, let into or countersunk in the upper part of the boss.

These pins or pivots, when so introduced from above into their places for use, are to be retained there, and prevented from rising, by the boss of the pintle being countersunk, or let into the wood of the rudder, which must fit close, and bear upon the pin or pivot and boss. The side braces or straps, and the bosses of the hanging pintles, as also the googings or braces, should be made stronger than the pins or pivots of such pintles.

It will be seen from this description, that any, or all, of these pins or pivots may be removed, and others (which should always be ready prepared and at hand) may be placed in their stead. To effect this it will be unnecessary to do more than to take off the said side braces or straps, or else to remove a sufficient portion of the wood of the rudder that bears upon the heads of the said pins or pivots, and bosses.

My improved bearing or friction pintle consists of similar side braces, or straps and boss, as the hanging pintle, and may

be made of the same materials as I have before pointed out, and is to be affixed in the same manner; but instead of inserting a cylindrical pin or pivot into the hole of the boss as hereinbefore described, I introduce a bearing stud, of any hard metal or combination of metals, into such hole, upwards from below. This bearing stud has a shank and a projecting head or nob on its lower end, which I make hemispherical, parabolical, flat, or in the form of a blunt inverted cone, and the shank that is to pass upwards into the hole of the boss of the pintle, must be so much smaller in diameter than the said protuberance as to leave a considerable shoulder to bear against the under side of the above-named boss; the shank that passes upwards through that boss, and the hole that receives it, must respectively be square, or of such a corresponding shape as to prevent the bearing stud from turning therein; or, for that purpose, it must have feathers or fins, as before mentioned respecting the head of the pin or pivot of the hanging pintle. The upper end of the said shank must pass through the boss, and project a little above it, in order that it may be there fixed by a forelock or cross key, or by riveting, or by a screw-nut, or any other sufficient means to retain it in its place, and prevent it dropping out.

The pins or pivots of the hanging pintles may be also introduced and secured in their respective bosses in the same manner. This friction or bearing pintle may work upon the usual googing, but in order to reduce friction, the friction or bearing pintle must work upon a counter or inverted friction pintle. The pin or stud of such inverted pintle is to be separate, and secured in its boss as before described, and formed either with a flat, convex, concave, indented, or hollowed end, or protuberance of head metal, for the purpose of receiving and supporting the underside of the corresponding protuberance, head, or stud, of the friction or bearing pintle of the rudder.

In fixing and applying these bearing or friction pintles, their respective positions upon the rudder and stern-post should be such, that the whole vertical pressure or weight of the rudder may be thrown upon them. Two of these bearing or friction pintles will, I conceive, be found sufficient for the rudder of a ship of one thousand tons, though more may be used. The number of hanging pintles may be such as may be found ne-

cessary to secure the rudder to the stern-post. Neither are these improved pintles limited as to the place or position they may be placed in on the stern-post and rudder, from head to heel, inclusive.

The friction pintles may be placed on the stern-post, and the hanging pintles on the rudder; or the hanging pintles may be attached to the stern-post, and the friction pintles to the rudder: and as many may of course be used as may, according to the size or quality of the vessel, be required.

I mean it to be understood, that my only claim, under my said invention, is for making the pin or pivots of the hanging pintles, and the bearing studs (or heads, and the pins to which they are attached) of the bearing or friction pintles, independently and distinct from the remainder of the pintles.

In Fig. 37 A is a rudder, and B the stern-post, of a vessel fitted with the improved hanging pintles at *c, c, c*, and bearing the friction pintles at *d, d*. In Fig. 38 A is a view of the back of a rudder which fits into B, a grooved stern-post in which the same hanging and friction pintles are shown in corresponding situations. Fig. 39 is an enlarged view of the hanging pintle and its corresponding brace or googing. Fig. 40 is the pin or pivot of that pintle, as it appears when detached from its brace, showing the fins that prevent its turning or falling through. The wood into which these pintles are fitted prevents these pins from rising, as shown in Figs. 37 and 38; and Fig. 41 is an enlarged view of the friction or bearing pintle, with its corresponding brace, to bear the weight of the rudder. Fig. 42 is the pin or pivot of the friction or bearing pintle in its detached state. Fig. 43 shows part of a chain, with a swivel joint, for towing a rudder end on in the event of its being knocked off, instead of towing it by the usual rudder pendants, which, giving an oblique direction, frequently occasions its loss.

Observations communicated by the Patentee.—This mode of constructing and fitting the rudder occurred to me after a serious accident, which happened to the Zenobia, a ship of 600 tons, which I commanded. We were running through the Torres straits from west to east, the only ship that has ever done so, when we struck on a sunken rock, and knocked off the rudder. Having hoisted it on board, I found the only injury

sustained was in the pintles, the pins being all broken at the neck. This misfortune, though trifling in itself, was the occasion of very great delay and expense, as we were obliged to make for Port Jackson, the nearest harbour where the pintles could be repaired, which we were a month in gaining; this was necessary, as we found no temporary expedient which we could devise would bring the ship under proper command. It then occurred to me how much better it would be to have the pins detached from their braces, so that by having a spare set on board when the pins broke, they might be replaced at sea, in as complete a manner as in a dock, thus avoiding all the trouble and danger which I experienced, in the above-mentioned case, of making for a port, and nearing the land, in an unmanageable condition, and then sending the rudder on shore, that the pintles might be taken off, moulds made, and the whole recast. Further, in cases where the broken pin remains jammed in the googing, a vessel must be docked or hove down to get it out. Now, in order to avoid so much disaster, and to give a ship the means within herself of readily repairing this most serious misfortune, I propose to construct the pintles in two pieces, the pins separate from the braces, and that they may be shifted or removed as occasion requires; and if damaged may be easily replaced, even at sea, by merely hoisting the rudder on board.

It is needless to particularise the numerous ships that have been entirely or nearly wrecked from not having the means of repairing their rudders at sea; as the frequent recurrence of damage to rudders, and the great danger attendant on it, must be familiar to every one at all conversant with naval affairs.

I have availed myself of the grooved stern-post, and adapted it to tow end on, if knocked off; but the grooved stern-post which is now used has a groove equal to the breadth of the fore part of the rudder, as shown in Fig. 44. This plan labours under the disadvantage of cutting deeply into both stern-post and rudder, besides leaving knife edges on the stern-post, which are very objectionable. By the plan which I propose, of applying a small circle to a large stern-post, as shown in Fig. 45, many advantages are gained, in facility of shipping and unshipping, snugness, diminished backwater, &c. &c., and the evils attendant on the old method are avoided.

PAPERS

ON

NAVAL ARCHITECTURE,

&c.

Art. IX.—*Chapman's Work on Ships of War, translated from the Swedish, by* Wm. Morgan, *of His Majesty's Dock-yard at Portsmouth.*

Of all the authors on naval architecture, Chapman is deservedly the first in rank: his genius, love of his profession, and sincere devotion to its interests, have rendered all his works on this science of the very highest value. Chapman may be considered pre-eminently as the champion of the theory of ship-building; and it may be observed, that he who was perhaps the greatest *practical* constructor of any country, was the most decidedly convinced of the absolute necessity of submitting all his investigations of the subject unreservedly to the direction of *theoretical* principles.

The distinguishing characteristic of Chapman's works on ship-building, is the application of the inductive method of philosophy to the different parts of the subject. His constant object was to found a theory on experimental results; and he never indulged in speculation or hypothesis, when the subject permitted him to conduct his investigations on actual measurement and correct observation. In those cases in which he had not sufficient data on which to found a theory, he conducted his investigations on the acknowledged principles of mechanics, and subjected his results to the test of observation and comparison. If, in a few instances, he departed from this method of investigation, he showed himself fully aware of the uncer-

tainty of the results; and it is to be remarked, that the exceptions to this general mode of his procedure were fewest in his latest works. He attempted to arrive at a complete theory of naval architecture. He sketched the outline with a master's hand; and if, in some places, the filling-in was imperfect, yet, as a whole, his works have never been surpassed.

The most celebrated work of this author is his "Treatise on Ships of War:" it was written when his scientific knowledge was improved, his experimental knowledge enlarged, and his judgment matured. It contains the result of all his labours on the subject. In his former works he gave the theory of the science, with an occasional application to the design of ships; but in this he collected and gave in detail all the data which affected the qualities of ships, calculated their effects under different circumstances, and determined on theoretical principles, deduced from his experience, the dimensions and forms of all ships of war, from a first-rate to the smallest armed vessel. Their calculated elements are collected in tables; and drawings of all the ships constructed agreeably to these elements complete the work.

The high reputation of this work, and the desire that the information it contained should be open to the English constructor, first induced the translator to undertake the rendering it into English; and he trusts that the knowledge this work imparts on this important subject, will be found generally useful in the design of our future ships of war. The translator has preferred giving a close rendering to a free translation, in order to ensure, as far as in his power, the true meaning of the author;—who appears rather to have attended to the matter he had to communicate than to the manner of his communicating it. The translator hopes that the faults he may have fallen into, if they should not be found of great consequence, may be forgiven, from a consideration of the numerous difficulties he had to contend with in a language so little known as the Swedish.

All the plates necessary to the illustration of the work will be given with the translation. The large sheer draughts, &c. of the different classes of ships given in the original, are necessarily omitted, on account of the very great expense their

engraving would have incurred. To a scientific constructor this omission will be of little or no importance, as all the dimensions and elements of design are given in the tables, from which the different draughts may be easily made.

Reference is made by the author to his other works, some of which have never been translated. It is intended, by the translator of the present treatise, to continue the rendering into English all the other works of this author, which have not been translated either into French or English, and which are likely to conduce to the improvement of naval architecture, as his time may permit.

Notes will be given at the conclusion of this translation.

"*A Theoretical Essay, to determine the Proper Size and Form of Ships of the Line, as well as of Frigates and Smaller Armed Vessels.*" By F. H. af Chapman, Vice-Admiral, Commander of the Order of the Wasa with the Grand Cross, Knight of the Order of the Sword, Member of the Royal Academy of Sciences, active Honorary Member of the Royal Academy of Military Science, and Honorary Member of the Royal Academy of Painting and Statuary at Stockholm.

This theoretical essay, to determine the proper size and form of ships of the line, is dedicated to the King, by his most humble and loyal servant and subject,

Carlskrona, 1806. F. H. af Chapman.

Introduction.

Before the explanation of the contents of this treatise is given, the qualities of ships which were formerly built will be considered; a knowledge of which can be obtained only from a short historical account of their size and armament, by which may be seen what alterations have been since made in ships, and what effects these alterations have at length produced. It

is useless to inquire into the circumstances of vessels when they were propelled with oars; when arrows, spears, stones, and rams, were their only weapons. This investigation should not commence before the period when cannon were first used at sea, when the vessels no doubt retained some similarity to the row-vessels used immediately before, with elevations for the soldiers forward and abaft. These elevations were at first used as castles, in which small cannon were placed, the vessels remaining still low in midships, in order that oars might be used as well as sails. As the advantageous effect of cannon became better known, a deck was laid, on which cannon were placed at certain distances apart, on both sides, along the whole vessel, when they were propelled only by sails; and as cannon, by degrees, obtained a more convenient form, and their great advantage in war became still more evident, and the men gained, by experience, greater confidence in using them, vessels were constructed still larger, to which another deck was added; so that they carried two tiers of guns, one over the other, with the castles continued fore and aft, when the vessels were armed with guns selected from those which were at hand, of such a size as the room for recoil would admit, and which it was considered they could carry with safety; which may be collected from the following account.

About the middle of the sixteenth century the *Mars* was built, which, on account of its uncommon size and armament, was called the *Incomparable.* It carried 173 guns, 125 of which were of copper; the dimensions of this ship are not known, but the armament was as follows :—

	Number.	Weight of the Shot.	Weight of the Guns.	Length of the Guns.	
		lb.	S. lb.	in feet.	in cal.
[1] Whole Cartauer........	2	50	32	14	22
¾ do.	4	40	25	14	23½
½ do.	8	25	16	12	24
Notslangor	3	25	24	16	31½
Fältslangor	16	10	11	13	35
¾ do.	14	7	7	12	36½
½ do.	20	4	4	11	40½
Double Falkonet	18	2½	2½	9	38
Single do.	24	1¼	1	8	43½
Falckuner	60	1	½		
Skärbräckor	4	¼			

The greatest part of this armament consists of very small pieces, so that not more than 67 of them can be considered as cannon; namely, the first six kinds, or the 47 guns, which may be supposed to have been placed on the two decks, and the 20 four-pounders forward and abaft on the castles, making together 67 cannon; the 42 smaller pieces on the two next lines, may be supposed to have been placed round on the top of the castles, as our modern swivels; and the 64 smallest pieces were a kind of small-arms or musketoon[2]. The proper

[1] All that relates to these ancient ships is taken from the voyages of the Swedish navy, by Lieutenant-Colonel Tornquist, and by Jacob Terngström, in the fourth part of the Transactions of the Royal Swedish Academy of Sciences.

[2] In the year 1564, it was the Admiral's ship, in a severe engagement with the ships of Denmark and Lubec, between Oeland and Gothland. The engagement took place under sail with several of the enemy's ships at the same time. It unfortunately happened, during the action, that some loose powder between decks took fire, which communicated with the magazine, and the ship was blown up. Probably ladles were used for the powder, cartridges not being then in use.

size and form of cannon were not determined in proportion to the weight of the shot before the beginning of the seventeenth century, when ships were first constructed to carry a previously-determined number of guns, which may be collected from the following table. It is also known, from history, that in the year 1628, when the *Wasa*, of 80 guns, half-cartauers, or 24-pounders, sailed from Skeppsholmen to Stockholm, with only the three topsails, in a light south-west wind, intended for an expedition to the Baltic, this ship did not proceed farther than Blockhusudden, or about fifteen or sixteen cables' lengths from Skeppsholmen, when it upset, and sank ten fathoms, so that all below the main cross-trees was under water.

That the *Wasa* carried 80 guns, probably on three decks, is credible; but that all the armament consisted of half-cartauers, or 24-pounders, must be considered to have been a mistake of the historian, for this reason; a ship which could carry such an armament, must have been nearly as large as the *Crona* (see the next table), in order that it might not upset, even in harbour, without the effect of the wind on the sails; but that it was not so large may be inferred from the circumstance, that the depth of the water where it sank was not more than 60 feet, and, consequently, if the lengths of the masts agreed with those of the ordinary ships of that period, it must, when grounded, have had an inclination of 30 degrees, when the main cross-trees were just above the surface of the water. It would also be considered as a very large ship, because it was built 30 or 40 years before the *Stora Crona.* The conclusion must therefore be drawn, that only the lowest tier of guns were 24-pounders, and that the two other tiers of guns were of less weight of metal; but that nevertheless the armament was too great for its size.

In the following table, A, which is an extract from several navy-lists, the oldest I could find, coming down to nearly the conclusion of the last century, different kinds of ships of war are found with very dissimilar armaments; but as the consideration of merely this table cannot give any correct information, whether the ships had greater or less dimensions, with respect to the weight of their armaments, it is necessary to find some other method, by which a comparison between their magnitude

and weight of armament may be formed. It is however, in the first place, necessary to mention the following particulars.

1. When the ships of war of all nations are compared with one another, it is found that there is a similarity in this particular circumstance, the form of the bottom; and that this similarity has existed from distant periods among all nations using open row-vessels, mentioned above; namely, that the form of the midship sections can be compared with a trapezium, with its sides inclining outwards, to prevent the sea from breaking over the gunwales, diminishing downwards from the water-line, and rounding at the bilge. The difference of the form of the midship sections of ships of war from that of the midship sections of these vessels, is chiefly in the tumbling home of the upper works, so as to form a fair continuation with the ship's sides.

2. It may be admitted, in regard to the subject under consideration, that all ships of the line have their depth or draught of water in a constant ratio to their breadth.

Consequently, if the length of a ship, from stem to sternpost, $= L$, and breadth $= B$, its magnitude or displacement is expressed by B^2L.

3. As ships of the line, like other machines, must be estimated by their effects, and as the effect of ships is produced by cannon, the effect of that ship is the greatest whose number of guns, multiplied by the weight of its shot, gives the greatest product, C. (See the Table.)

4. As the ship is designed for the guns, its magnitude must be proportional to the weight of the armament, or to C; and when a comparison is made between the armaments of greater and smaller ships of the line, *such as they were in the middle of the last century*, their magnitude and stability will be rightly expressed, when B^2L is equal to about $2900\ C^{\frac{2}{3}}$.

Put $\dfrac{B^2L}{2900\ C^{\frac{2}{3}}} = m$; when $m = 1$, the magnitude of the ship is in a proper proportion to the weight of its armament; but when the quotient m is less than 1, the ship is too small. Put $B = \dfrac{L}{n}$, then $L = \sqrt[3]{2900\ n^2 m\ C^{\frac{2}{3}}}$; if the magnitude of the

ship should bear the same proportion to its armament, as was usual about the middle of the last century; then $m = 1$, and $n = 3{,}82$.

When these values are substituted in the equation just mentioned, the length is obtained, which is inserted in the second column of the table from the right hand, under the heading: *the proper dimensions*, viz. in proportion to the weight of the armament; and the breadth is equal to the length divided by 3,82.

The product B^2L is not a sufficient evidence of which ship is the best, for the circumstance of the greatest breadth continuing before and abaft the middle, affects both the stability and the displacement; but although this is by no means the only defect in the table, yet, for the present purpose, this rule may be considered very good.

Should it be asked, what was the size of the *Makalos?*—As this ship was in an engagement in the year 1564, and nothing is said of its stability, it must be supposed to have been as stiff as ships of that period usually were; thus it may be supposed that $m = 0{,}8$, and $n = 3{,}8$: when these values are substituted in the foregoing equation, it will be found, that its length was about 164 feet, and the breadth 42 feet; dimensions which, 240 years ago, must have constituted it an unusually large ship.

In the consideration of this table, it is the quantity m which immediately engages the attention, which is perceived to be very small for those ships which were built near the end of the 17th century; which may be, in a great degree, accounted for from the precaution which was taken with them: 1. they had not heavy rigging; and 2. they took so much ballast that the height of their lower battery was generally not more than about $3\frac{1}{2}$ feet above the water; so that in a strong wind they could not engage in any service, because they could not venture to open their lower tier of ports.

These ships could never carry provisions for more than three months; and as the fleet at that time was stationed at Stockholm, it was necessary that they should be attended by vessels to carry provisions, that what was consumed during the long coasting voyages, might be replaced, in order that they might

keep their three-months' provisions in reserve when they went to sea.

The many different values of *m* are to be accounted for by the following reasons: 1. As foreign builders from Germany, England, and Holland, were employed in building the ships, especially in the 16th and first half of the 17th century, who, from their state of knowledge, could be regarded only as mechanics, each of whom adopted the method he had seen and learnt, it so happened, that the ships which were built to carry a certain number of guns, were very different in size; 2. When a ship was built to carry a certain number of guns, the commander-in-chief determined the size of the guns; 3. The master rigger independently determined the lengths of the masts and yards: that is, one built a ship, another determined its armament, and a third gave the masts and yards,—each according to his own notions. This was in a great measure the cause, that from the middle of the 16th to the end of the 18th century, no particular improvement took place in the ships.

Of all the ships here mentioned, the *Stora Crona*, which had brass guns, was the worst, as appears by the quantity $m = 0{,}639$. When this ship, in the year 1676, was in an engagement with the Danes and Dutch, in Calmare Sound, it upset in tacking; the cause assigned is, that this operation was not performed with the care which the crankness of the ship required, which arose from the ballast having been taken out of the hold, by which the draught of water was diminished seven feet, which is, no doubt, an error of the press. If all the ballast and every thing else in the hold had been taken out, the ship would not have been lightened seven feet; but if about 600 skipponds of ballast were taken out, it would have been lightened seven inches, which is probable. But, at all events, this ship was too small in proportion to its armament, as may be seen from the last two columns on the right hand of the table: *the proper dimensions, length and breadth.* When these dimensions are compared with those which the ship really had, it appears improbable that it should float without immediately upsetting; to prevent which, it was necessary to take so much the more ballast, and provisions for only three months, and water for half that time, when the height of the lower battery was about $3\frac{1}{2}$ feet, as was

just mentioned. And as ships of that period had not great areas of sails, and consequently had small masts and light rigging; and as it was never customary to form a line of battle close hauled; this ship could scarcely be much tried in light winds, even with the little stability it possessed.

The *Enighet*, of 94 guns, which had two tiers of 24-pounders (see the Table), and was found in the year 1732 to be deficient in stability, had the following alteration made in its armament: 24 24-pounders, 26 18-pounders, and 28 8-pounders; in all 78 guns; when her name was changed to the *Konung Fredrik*. For the same reason the armament of the *Carolus*, of 108 guns, was altered as follows: 30 24-pounders, 28 18-pounders, 28 8-pounders, and 14 4-pounders; in all 100 guns. This alteration was no doubt made to prevent the disorder and delay which occur in serving the powder and shot in action, when guns of different calibre are placed on the same deck.

But what particularly demands attention in the consideration of the quantity m, is this; that during nearly two centuries the fleet did not receive any improvement, by an increase in the size of the ships in proportion to the weight of their armament. The *Stockholm* was built in the year 1708, in which ship $m =$ 0,833, and was thus worse than that built in 1667, in which $m = 0,935$; which is the more remarkable, as at that time a great number of ships were built with a view to permanently keep up a fleet for the defence of the kingdom.

The mode of attack at that time explains the reason why the ships were so small in proportion to the weight of their armament. When two hostile fleets met, the foremost ships immediately commenced the attack, either to board, sink, burn, or wreck each other; so that the sails were most in requisition before the commencement of an engagement, to get to windward and come to action; and at length for the ships, which could not sustain the action, to escape as quickly as possible; and as it was never necessary to engage with all sails set, in high winds, close-hauled, as now practised, neither was it necessary that the ships should be much stiffer than they then were. But about the middle of the last century, when this method of fighting was already practised by other nations, it

could not be unknown to him or them who had the direction of the naval affairs of the kingdom; and in order that the ships of the Swedish navy should possess as good qualities as those of other nations, it was necessary that the ships which were to be built should be constructed in reference to it; but that it certainly was not known on what the stability and good sailing depended, which were necessary in such manœuvres in action, may be seen from what follows.

In a regulation which was published in the middle of the 18th or last century, the dimensions of ships of 70, 60, and 50 guns were determined, (according to which three ships were built in the years 1756 and 1758, see the Table,) and in which, among other things, is the following observation: "that the greatest increase in comparison with ships formerly built, took place in the length and depth; because better sailing, among other things, cannot be obtained in any other manner; both the length and depth being strictly in reference to this object in the relation between the three ships of different sizes: but great breadth is given to afford properly, sufficient room for the guns." Reasoning which certainly does not give the best prospect of the improvement of the fleet.

As such a principle, when the improvement of the fleet was the object, could not escape the observation and examination of thinking men, a commission was commanded by the King for the improvement of certain ships, which made, on a reasonable principle, with the gracious approbation and confirmation of his Majesty, a new rule, by which two ships were built in the years 1774 and 1775. (See the Table.)

In this manner ships at length came to be built of such a size, as to be in some degree adapted to the weight of their armament, and to the method of engaging in action then practised, as appears from the quantity $m = 1,123$, by which they obtained such a moment of stability, as to use their lower-deck guns in action in a topsail breeze.

The following table is an extract from several navy-lists.

TABLE A.

SHIPS' NAMES.	Total of Guns.	Deck.	Weight of Metal, and Number of Guns.									Number of Crew.	When built.
			36	30	24	18	12	8	6	4	3		
Cronan	126	1	12	16	4	2	..	..	..	..	..	885	In action in 1676.
		2	..	..	36	..	..	..	..	..	..		
		3	..	..	..	..	36	..	..	..	..		
		4	..	..	..	..	..	..	20	..	..		
Svärdet	86	1	12	4	14	..	..	..	..	..	..	704	
		2	..	..	..	..	26	4	..	..	..		
		3	..	..	..	..	..	20	..	..	6		
Nyckelen	86	1	..	..	26	..	..	..	..	..	..	576	
		2	..	..	..	..	30	..	..	..	..		
		3	..	..	..	..	..	10	12	2	6		
Draken	64	1	..	..	12	14	..	..	..	..	..	454	
		2	..	..	..	..	18	6	..	..	..		
		3	..	..	..	..	..	..	12	..	2		
Hieroninus	70	1	..	..	..	..	28	..	..	..	..	324	
		2	..	..	..	..	6	18	..	..	..		
		3	..	..	..	..	..	..	..	8	10		
Amaranten	50	1	..	..	..	..	18	4	..	..	..	280	
		2	..	..	..	..	..	..	20	..	8		
Hercules	62	1	..	..	..	24	..	..	..	..	..	320	
		2	..	..	..	..	..	..	22	..	..		
		3	..	..	..	..	..	..	..	14	2		
Wrangel	70	1	..	..	22	2	..	..	..	..	..	448	1662
		2	..	..	..	..	..	22	..	..	..		
		3	..	..	..	..	..	..	20	..	4		
Bohus	74	1	..	..	..	26	..	..	..	..	..	400	1663
		2	..	..	..	..	..	28	..	..	..		
		3	..	..	..	..	..	..	..	18	2		
Uppland	78	1	..	..	22	2	..	..	..	..	..	452	1666
		2	..	..	..	..	..	26	..	..	..		
		3	..	..	..	..	..	..	16	..	4		
Finland	64	1	..	..	..	24	..	..	..	..	..		1667
		2	..	..	..	..	..	24	..	..	..		
		3	..	..	..	..	..	..	..	14	2		
Sverige	70	1	..	..	24	..	..	..	..	..	..	596	1678
		2	..	..	..	24	..	..	..	..	..		
		3	..	..	..	..	8	2	6	6	..		
Stockholm	72	1	..	..	22	4	..	..	..	..	..	536	1682
		2	..	..	..	..	26	..	..	..	..		
		3	..	..	..	..	..	16	..	..	4		
Drottn. Hedv. Eleonora	90	1	..	..	30	..	..	..	..	..	..	630	1683
		2	..	..	..	2	28	..	..	..	..		
		3	..	..	..	..	..	..	22	4	4		
Drottning Ulrica	82	1	..	..	26	..	..	..	..	..	..	690	1684
		2	..	..	..	24	..	..	..	..	..		
		3	..	..	..	..	24	..	..	..	..		
		4	..	..	..	..	..	..	4	..	4		

TABLE A.

SHIPS' NAMES.	Ships' Dimensions. Length from stem to stern-post. L.	Breadth moulded B.	Draught of water abaft.	Effect C.	Quantity. m.	Proper Dimensions. Length.	Breadth
Cronan	178½	43½	21	2460	0,639	197,4	51,7
Svärdet	159½	42⅙	20	1410	0,717	174,5	45,7
Nyckelen	154	37½	18½	1162	0,676	167,2	43,8
Draken	140	37	18	882	0,718	157,3	41,2
Hieroninus............	140	36	17	614	0,866	145,0	38,0
Amaranten	125½	28½	14	392	0,656	131,3	34,4
Hercules	134	33½	14	626	0,709	145,7	38,1
Wrangel	146	38	18	872	0,796	156,8	41,0
Bohus..................	140¼	36	17½	770	0,746	152,6	39,7
Uppland...............	142	38	17½	880	0,770	157,2	41,2
Finland	150	37½		686	0,935	145,5	38,1
Sverige	160	40	19½	1180	0,790	167,7	43,9
Stockholm	153	39	18	1052	0,776	163,4	42,8
Drotn. Hedv. Eleonora	168	41	21	1252	0,838	170,0	44,5
Drottning Ulrica	170	42	20	1380	0,834	173,7	45,5

TABLE A.

SHIPS' NAMES.	Total of Guns.	Decks.	Weight of Metal, and Number of Guns.									Number of Crew.	When built.
			36	30	24	18	12	8	6	4	3		
Götha....................	78	1	..	..	24	2	..	..	..	..	..	556	1686
		2	..	..	..	..	24	..	2	..	..		
		3	..	..	..	..	..	16	8	..	2		
Prinss. Ulrica Eleonora	80	1	..	..	26	..	..	..	..	..	..	546	1690
		2	..	..	..	..	24	..	..	..	..		
		3	..	..	..	..	..	..	24	..	..		
		4	..	..	..	..	..	..	..	..	6		
Pommeren................	56	1	..	..	..	22	..	..	..	..	..	336	1692
		2	..	..	..	..	..	22	..	..	..		
		3	..	..	..	..	..	..	..	10	2		
Carolus	108	1	10	..	22	..	..	..	..	..	..	850	1695
		2	..	..	..	30	..	..	..	..	..		
		3	..	..	..	..	..	28	..	..	..		
		4	..	..	..	..	..	..	..	18	..		
Enigheten	94	1	..	..	28	..	..	..	..	..	..	795	1696
		2	..	..	28	..	..	..	..	..	..		
		3	..	..	..	..	..	28	..	..	..		
		4	..	..	..	..	..	..	..	6	4		
Prins. Carl. Fredrik.........	70	1	..	..	26	..	..	..	..	..	..	532	1704
		2	..	..	..	..	26	..	..	..	..		
		3	..	..	..	..	..	..	18	..	..		
Stockholm................	60	1	..	..	24	..	..	..	..	..	..	474	1708
		2	..	..	..	..	22	..	..	..	..		
		3	..	..	..	..	..	..	14	..	..		
Riksens Ständer	64	1	..	..	24	..	..	..	..	..	..	492	1744
		2	..	..	..	..	24	..	..	..	..		
		3	..	..	..	..	..	..	16	..	..		
Drottn. Lovisa Ulrica	72	1	..	..	28	..	..	..	..	..	..	628	1745
		2	..	..	..	26	..	..	..	..	..		
		3	..	..	..	..	..	..	18	..	..		
Södermanland............	52	1	..	..	..	22	..	..	..	..	..	350	1749
		2	..	..	..	..	..	22	..	..	..		
		3	..	..	..	..	..	..	..	8	..		
Drottning Sophia Magdalena	70	1	..	..	28	..	..	..	..	..	..	600	1758
		2	..	.	..	..	..	..	..	..	..		
		3	..	..	.	..	..	..	16	..	..		
Prins. Carl................	60	1	..	..	24	..	..	..	..	..	..	500	1758
		2	..	..	..	..	24	..	..	..	..		
		3	..	..	..	..	..	..	12	..	..		
Lovisa Ulrica, was an East Indiaman, sunk outside the Winga	50	1	..	..	..	22	..	..	..	..	..	380	1756
		2	..	..	..	..	22	..	..	..	..		
		3	..	..	..	..	..	..	6	..	..		
Kong. Adolph Fredrik and Gustaf 3..............	70	1	..	..	26	..	..	..	..	..	..	620	1755
		2	..	..	..	28	..	..	..	..	..		
		3	..	..	..	..	..	16	..	..	..		
Prins. Fredrik Adolph	62	1	..	..	24	..	..	..	..	..	..	584	1774
		2	..	..	..	26	..	..	..	..	..		
		3	..	..	..	..	..	..	12	..	..		

TABLE A.

SHIPS' NAMES.	Ships' Dimensions. Length from stem to stern-post. L.	Breadth moulded. B.	Draught of water abaft.	Effect. C.	Quantity. m.	Proper dimensions. Length.	Breadth
Götha	153	39	18	1094	0,756	165,0	43,5
Prinss. Ulrica Eleonora	158	40	19	1074	0,831	164,3	43,0
Pommeren	135	34	17	618	0,742	145,3	38,0
Carolus	180	47	23	1724	0,952	182,6	47,8
Enigheten	175	$44\frac{2}{3}$	21	1604	0,878	179,6	47,0
Prins. Carl. Fredrik	166	42	$18\frac{1}{2}$	1044	0,981	163,3	42,7
Stockholm	151	39	17	924	0,833	158,9	41,6
Riksens Ständer	$154\frac{1}{2}$	$41\frac{1}{2}$	19	960	0,943	160,2	41,9
Drottn. Lovisa Ulrica ..	$167\frac{1}{3}$	$44\frac{1}{2}$	20	1248	0,986	169,9	44,5
Södermanland	142	38	19	604	0,989	144,5	37,8
Drottning Sophia Magdalena	171	$44\frac{1}{2}$	23	1236	1,014	169,5	44,4
Prins. Carl.	160	42	$21\frac{1}{2}$	936	1,017	159,3	41,7
Lovisa Ulrica, was an East Indiaman, sunk outside the Winga ..	147	39	$19\frac{1}{2}$	684	0,993	148,6	38,9
Kong. Adolph Fredrik and Gustaf 3	174	$46\frac{2}{3}$	$21\frac{1}{4}$	1256	1,123	170,9	44,5
Prins. Fredrik Adolph.	169	$45\frac{2}{3}$	21	1116	1,123	165,7	43,4

That ships of the line have at length arrived at their present size and perfection, is especially to be attributed to the French Marine. Although the subject was treated on a false theory, namely, that the effect of the water on the ship's bow, is as the square of the sine of the angle of incidence, without regard to the effect of the water on the after part of the ship; yet it has conduced in the following manner to an increase in the size of ships, and to the good qualities they now possess in comparison with former ships. 1. To render them good sailers, their bows were made sharper than they commonly were. 2. It was then necessary to give them a proportional fineness abaft in relation to the bow, so that the centre of gravity of the displacement might be situated a little before the middle of the ship's length. 3. As the sharpness at both ends necessarily would diminish the displacement, and as the armament remained the same, the displacement must also be the same, so that it was necessary to increase the dimensions. 4. By this increase the distance between the metacentre and the centre of gravity of the ship became greater, by which the stability was increased to oppose heeling; and with the same inclination was capable of carrying a greater area of sail in proportion to the resistance of the water, and was therefore a better sailer.—Under all these alterations, the ⊕ section of the ship retained its similarity to a trapezium.

In this manner by practice, ships have approximated gradually to their proper size: it was not possible to arrive at any theory sooner, because it is the same with ships of war as with most other mechanical constructions; a correct theory cannot be given, before they are arrived nearly at perfection.

It appears from this reasoning, that it is now possible to foretell the qualities which may be expected in a good ship of the line.

When the qualities of ships are taken into consideration, together with the manner in which naval warfare has been carried on for a long time up to the present period, it appears, that the qualities of ships determine the manner of giving battle at sea; and in short, as the manner of engaging is now capable of being determined, so by a good and well-grounded theory the necessary qualities can be given to a ship of the line; and

to determine these qualities, a certain case must be supposed, in which the principal of them are brought into action, which certainly happens when many ships are engaged. Let us therefore suppose an engagement with two hostile fleets.

The hostile ships are ranged in straight lines, parallel to, and within gunshot of, each other, and in such a direction with respect to the wind, that they lie within six points of it, each succeeding ship sailing in the wake of the ship ahead, about 50 fathoms apart; and in a stiff top-sail breeze, with the three topsails, top-gallant-sails, fore topmast stay-sail, jib and mizen, they must not incline more than 7 degrees; they must be capable of using their leeward lower-deck guns without danger in a heavy sea, be good sailers, and work well to windward, with this condition: that although the ships may be of different sizes, and carry different weights of metal, yet that in equally high winds, with the same sails set, their inclination must be nearly the same, (so that their guns may be worked with equal convenience,) that they must be equally good sailers, and under all circumstances, manœuvre alike.

Of two hostile fleets, which attack each other, that fleet which is composed of the stiffest and best-sailing ships, is master of the attack, and can begin and end it at pleasure. But as the operations of many such ships together, although of different sizes, should at once produce the same effect as if they constituted but one machine, it is necessary that they should keep in company, and be effective in proportion to their size. As they must sail equally well, the area of their sails must be proportional to the resistance they experience from the water: and as all the guns must be used and worked alike, their inclination must be nearly the same; so that the form of the ships below the water will be in some degree adapted to the same area of sails; hence it is found, that when a ship of the line is to be constructed, the body of the ship and the sails are to be considered as constituting the ship. The theory also which regulates the design of the ships which act together in a line of battle, is more difficult, than the theory which regulates the design of ships which are not intended to act in company.

Thus the qualities of ships of the line are now correctly determined, so that, with the help of theory, their proper

size and form [1] can be given to them in reference to these qualities.

Although all the rules of art may be attended to in the construction of a ship, it may happen that it may not behave well, for the following reasons: 1. If the sails are badly cut and made, so that the wind is prevented from producing its full effect on them, by which not only is the sailing close-hauled injured, but also the facility of coming about is diminished. 2. Also in the behaviour of a ship in manœuvring under sail: for if all the sails are not set advantageously in respect to the direction of the wind and the ship's course, it will lose both in weathering and in velocity, as well as in quickness in tacking. And, 3. Attention must also be paid to the trim of the ship, and to the adjustment of the position of the masts and yards, which have a great effect on a ship's qualities. Such are the reasons, that it so frequently happens, that a ship may in one voyage possess very bad, and in another, very good qualities, or at one time be a very bad sailer, and at another a very good sailer.

From this it may be inferred, that although a ship's form is such that it possesses the best qualities, they can never be brought into action, until it is properly rigged and worked, by a commander skilful in seamanship and tactics, as, besides what is here mentioned, other circumstances which may prevent a ship's good sailing must be attentively considered.

It must not be concluded, from what is here said, that there is any deficiency in such knowledge as is necessary in rigging and manœuvring a ship properly; on the contrary, the ships of war of the Royal Navy have officers of every rank who may be compared in their knowledge of the science with the best officers which any maritime power possesses; but it is not so common as in those nations which have large colonies in all parts of the world, which always afford opportunities of improvement by experience, which Sweden does not possess; but it is for the younger and less experienced of this class that these hints are given.

The reason that ships of the line were generally so much

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[1] On this subject see "Grunder till Kännedom af linie skepp;" printed at Stockholm, in 1796; which, together with a little treatise "On the Area of the sails of Ships of the Line," should accompany this work.

improved in size and in the number of their guns, in little more than half a century, is this: ships of 50 guns were first considered to be too small, and then those of 60 guns. Ships of 60 guns may be as complete, as to their class, as ships of 70 guns; but it is also equally certain, that the larger ship with the heavier armament produces a greater effect than the smaller ship with less weight of metal.

The reason that ships of 60 or 64 guns are now considered to be too small to use in a line of battle is, that when two nations carry on a war with ships of 60 guns, one of the nations in order to obtain the advantage in the next war, builds ships of 70 guns of heavier metal; and when the other nation finds itself too weak, it also provides for the next war ships of 70 or 74 guns, to compose the main body of the fleet in battle: and the increase has now probably stopped. The forests cannot produce a sufficient quantity of large timber for greater ships; it may, on the contrary, happen, that sometime hence, it may be necessary to return to smaller ships; but that ships will continue to be built as long as possible of their present magnitude, may be inferred from what follows.

In the first place the following question must be considered: Is the effect of cannon shot greater or less than in the proportion of their weight? The hole or fracture which a shot makes in a ship's side or any wood-work, is as the area of its section; thus a shot of double the weight of another makes a hole 60 per cent. greater than the other; and as the force which propels them is in proportion to their weight, the depth they enter into the ship's side is in proportion to their diameter; consequently the effect of a shot is as its weight. And when the smaller shot pass through a ship's side, they cause a small splintering; whereas when the larger shot pass through, they cause a great splintering, especially when they strike the waterways or knees; thus it may at all events be admitted that the effect of cannon shot is as their weight.

This objection may be brought against the use of heavy metal, that what is gained by the effect of larger shot, is lost in the number; but this objection is removed by the use of traverse carriages. See "Kännedom af linie skepp," and the note to § 4.

The object of this examination is, to be able to make a comparison between the effect of the guns and the whole expense of the ship, also between the same effect of the guns and the number of the crew, which two articles, namely, the ship with its armament, and the crew with their provisions, constitute the total expense of a naval war. It was said, that ships will continue to be built, as long as possible, of their present magnitude: the meaning was this, that a greater effect is produced by large ships in proportion to their expense, than by smaller ships, the proof of which will be given.

In the same treatise will be found the number of guns and the weight of metal for each ship; and when the number of guns is multiplied by the weight of shot for each ship separately, the product for a ship of 66 guns is 1752, for a ship of 74 guns 1920, for a ship of 80 guns 2244, for a ship of 94 guns 2796, and for a ship of 110 guns 3528, which numbers will express the effect of the guns.

The complements of the crews of these ships are 606, 658, 706, 848, and 1000.

Table showing the different Weights in Cubic Feet of Water.

(See the same Work.)

Number of Guns.	66	74	80	94	110
Guns with all connected with them. Table No. 4.	11282	13042	15129	18758	23549
Ballast..............Table No. 5.	8762	9627	11146	14193	18179
Hull, rigging, &c.....Table No. 11.	51588	55848	61910	73255	86255
Total	72232	78517	88185	106206	127983

As it has been found, that these numbers are very nearly proportional to the expense of the ships with their furniture and armament complete, respectively, they are here admitted as proportional to the expense of the ships. To make the required comparison clear, it may be best to adopt the following method: 1. All the numbers which express the effect of the guns are divided by 1752, and multiplied by 1000; 2. All the

numbers which express the complements of the crews, are divided by 606, and multiplied by 1000; 3. All the numbers which express the expense of the ships are divided by 72232, and multiplied by 1000. In this manner the following table is obtained, which shows the comparison between the ships.

Number of Guns.	66	74	80	91	110
Comparative effect of the armaments	1000	1096	1281	1596	2014
Comparative numbers of the crews	1000	1086	1165	1399	1650
Comparative expense of the ships ..	1000	1087	1221	1470	1772

This table is to be understood thus: if the effect of the guns of a ship of 66 guns is to the expense of the same ship as 1000 : 1000, the effect of the guns of a ship of 110 guns to its expense is as 2014 to 1772, or as 1000 : 880; and if the effect of the guns of a ship of 66 guns is to the expense of the crew as 1000 : 1000, the effect of the guns of a ship of 110 guns is to the expense of its crew as 2014 : 1650, or as 1000 : 819; and so on.

Hence it appears, that the effect of the guns, in relation both to the expense of a ship and to the number of the crew, is greater in large than in small ships: and that therefore it is the greatest economy to have large ships and heavy metal; which was to be shown.

This also answers very well for Swedish ships of war, whose crews consist generally of hardy and strong men, which may be inferred from this circumstance; that in the last Russian war, the men at the guns in some of the ships did not give themselves time to use the tackles, but put their breasts to the 36-pounders and carriages, when it was necessary to run them in or out, and one man at the foremost axle trained the gun to the middle of the port.

On a consideration of all that has been said in this introduction, it appears that it is now high time that theory should be brought to the aid of practice, in order that the proper size and form may be given to ships of the line.

The manner in which the subject is here treated may be best understood from the treatise itself; each chapter will however be noticed, that a notion may be formed of the contents of the treatise, and observations will be made where necessary.

Chap. I. determines the nature of the armament, &c. of those ships, which are considered fit to be placed in a line of battle, which are called line-of-battle ships.

That all the classes of line-of-battle ships, of which a fleet is composed, are taken into consideration together, is on this account: that as the ships which should form a line of battle, although of different sizes, must act as one machine, it follows, that in certain respects they must all possess the same qualities, as was said above; but as ships of different sizes cannot be similar, if they possess the same qualities, the rules according to which the ships are designed must be of such a nature, that the same rule will give the same qualities to different ships.

The reason that two kinds of ships (74 and 66 gun ships) are mentioned as forming the body of the battle is this, that one may be chosen, because it is not consistent with a good disposition of force to have a fleet composed of many classes of line-of-battle ships.

In the note to section I. it is said, that the weight of the shot is $\frac{1}{3}$ greater than the nominal weight of the metal of the gun; but it is nearly $\frac{1}{4}$ greater. Swedish cannon shot are heavier than those of other nations of the same described weight.

From what has been said before in this introduction, it may be inferred, that the armament here proposed is not too heavy, especially if the lower-deck guns of the three largest classes of ships are placed on traverse-carriages, when 48 and 42-pounders can be conveniently used; nor is a 48-pound shot too heavy for our men to carry to the muzzles of the guns. Carronades are never reckoned in the number of guns of a line-of-battle ship, if there are any, as they are considered only as supernumerary.

The time for which the ships are provisioned is taken at 6 months, but for the two largest classes at something less; and they have a little less height of battery.

It is necessary to adapt the draught of water of ships, in some

degree, to the depth of the water where they will navigate; but by means of a lee-board it must be increased about $\frac{3}{4}$ of a foot, to diminish the leeway.

Chap. II. On the displacement of a ship, and from what it is obtained.

It is obtained, 1. from the total weight of the armament with every thing connected with it; 2. from the weight of the ballast, which is in proportion to the armament; 3. from the provisions and water *m, m,* which are in proportion to the number of the crew and the time for which they are victualled; and 4. from the weight of the ship itself, with every thing relating to it.

In the note to section 8, it is said, that a part of the crew may be lodged on the orlop deck; the meaning is, that the sick of the crew should have a berth there, fitted up with beds, between the main and fore hatchways.

Chap. III. Method by which the length and breadth of a ship should be found. Wherein it is shown, that at first, only by practice and by approximation, the magnitude of ships was determined, and their length and breadth proportioned in a certain relation to the stability they must possess, to carry a certain area of sail, by which they would sail equally well; and afterwards general rules on theoretical principles are given in this work, for the design of the draughts of all kinds of ships of the line.

The length at first found may be constant, but not the breadth; an approximation to it may be first made until the area of sails is determined, when the true proportion of the breadth is fixed accordingly. The conclusion of this chapter gives a description of what is meant by the construction-element, (*amne,*) by which a ship must at first be formed.

Chap. IV. shows the manner of making the construction-element, so that the direction of the diagonals which form the ships' after-body may agree with the relaxation-line.

In respect to the application of this line, and on account of the fulness of ships, which decreases as they are smaller, and to obtain a moderately full quarter, this construction-element must consist of two parts, one above the other; and this method of construction requires two ⊕ sections.

Chap. V. To form the construction-element for a ship of 110 guns.

The lower element is generally, for all line-of-battle ships, composed of three parts: the after part is drawn mechanically, and its superficial content calculated, as well as the situation of its centre of gravity, from the middle of the length of the whole element; the length of the middle part is the distance between the two $\oplus$ sections, which contains its known area; and the length of the fore part is equal to the distance from the foremost $\oplus$ section to the stem, and its form is that of a parabola, yet unknown. The common centre of gravity of the three parts will be at a given distance abaft the foremost $\oplus$ section; and the exponent of the parabola is found, and consequently its area, so that the common centre of gravity of the three parts may agree with its already determined situation. When the upper element, which is a parallelopipedon, is added to the lower, the whole element is obtained, whose solid content is equal to that of the ship's displacement; but the end before the foremost $\oplus$ section must be altered to another parabola, the depth of which is from the foremost end of the upper element; the line called the line of sections is then first obtained, which determines all the areas of the sections. The Table No. 15 is then given, which contains the expressions and calculations relating to this method of construction; and the chapter concludes with observations on the rake of the sternpost and the form of the stem.

Chap. VI. To form the load-water section.

This section is the most important in the whole construction, and is the principal element, not only in a ship, but in all floating bodies; its form at the extremities is not very material, only it must be observed, that any alteration at these parts must not alter the moment of stability, $\int^{3} y^3 dx$.

The construction of the breadth-lines then follows.

Chap. VII. On the form of the $\oplus$ section.

In this chapter the difference between a line-of-battle ship and a merchant ship is considered; and in a note to section 21, a case is mentioned, in which the form of the $\oplus$ section of a merchant ship requires to be nearly the same as that of a line-of-battle ship.

It is known, from experience, that a stiff ship, which has its common centre of gravity of ship and lading below

the water-line, rolls hardly, and the lower it is situated the more violent is the rolling; whereas a ship which has its centre of gravity in, or something above, the water-line, and is nearly as stiff, never rolls violently. See more on this subject in section 10 of the Treatise on Ship-building, printed in 1775.

With the usual form of ⊕ section, the centre of gravity of the hold is situated low, and consequently that of the lading; and it is found that such a ship, laden with salt, rolls hardly, because its common centre of gravity is below the water-line; if the ship, with such a lading, had the form of bottom recommended in this work, the heavy rolling would not take place, and the ship would thereby be more easy. A ship of this form would also have sufficient stability to sail with less ballast than usual; consequently all merchant ships should have the same form of ⊕ section as is here recommended for line-of-battle ships.

It is shown, as well by calculation as by construction, that the distance between the centre of gravity and the metacentre is greater with the form of ⊕ section here recommended, than with that hitherto common, and consequently the ship has the greater stability to oppose heeling; and this leads to the formation of three laws for all floating bodies. It has also been deduced, from a comparison between ships which have been built, that those constructed according to the principle here recommended, are stiffer than those which have the common form of ⊕ section. In conclusion,[1] the manner of constructing the ⊕ section according to this principle is shown: though this method of construction may not be exactly followed, the form must be such as very nearly to agree with this principle.

Chap. VIII. To construct the sections before and abaft the ⊕ section.

This chapter explains the method of forming from the line of sections *k* another line C, which is the true line which governs the form of the sections, and assists in obtaining their areas.

The methods which are used for this purpose are inserted

[1] See more on this subject in the "Treatise on Ship-building," printed at Stockholm in 1775.

in the upper part of Table 22 for each ship separately, the after sections on the left-hand side, and the fore sections on the right. Calculations are made from these sections, and the results are inserted in Table 23.

The curved lines, which are drawn below the water-lines on all the sheer draughts, and marked C, are the true lines; and the ticked lines are the lines of sections, marked *k* and k on the draughts, constructed by the relaxation-lines; and those marked *h* and h on the draughts, constructed by the parabolic method. The double circles on all these draughts are the common centres of gravity of the ship and lading, completely rigged and armed. The small single circles below the water-lines are the centres of gravity of the displacement; and the single circles above the water-lines are the metacentres.

Chap. IX. On a ship's upper works.

This chapter shows what determines the tumbling home *m*,*m*, of the top timbers; also gives the reason why ships' sides are made so thick by the outside planking.

For the convenience of working the ship, the quarter-deck, forecastle, and waist, are now connected, so as to form a flush deck, with hatches, in midships, to admit of the launch being stowed below on the upper deck; the spare gear is placed close to these hatches, by which all obstructions to working the guns are removed.

As the object of the head is the security of the bowsprit and the convenience of the ship's company, and as all unnecessary weight should be avoided, it is made as small as possible, and consistently with this arrangement, a suitable, but not an abundant, quantity of ornamental work is given to it; and as it prevents the use of the bow guns on the upper deck, it is intended, that in all these ships, the foremost forecastle gun on each side shall be a light 18-pounder instead of a 12-pounder, that when occasion requires it, it may be fired over all. The way used by the ship's company to the head is never through, but always over, the forecastle berthing.

That the cat-heads are placed so far abaft the stem is for this reason; that the weight of the anchors may not have so great an effect in pressing down the bow as if they were further forward; the space also before the forecastle ports is greater, and

gives more room, to conduce to the cleanliness of the ship's company.

The same principle is followed for the stern and quarter galleries as for the head of the ship; light, but no superfluous ornament is given, adapted to the circumstances of a floating body.

It is intended, if the 94-gun ship shall be the principal ship of a fleet, that the upper works abaft shall be built as shown on the draught, for cabins for the captain and other officers of the ship; but this is intended only for the principal ship of a squadron or division of a large fleet, otherwise the ship is to be without these upper works, by which the appearance of the ship will be improved.

Chap. X. To find the resistance which a ship experiences in moving through the water.

The resistance of the five ships of the line, and of the double frigate of 52 guns, is calculated for finding the areas of the sails, and the results are at the conclusion inserted in Table No. 26.

Chap. XI. On the area of sails, which is the force which propels a ship forward: this force is directly as the resistance of the water, and reciprocally as the weight of the ship raised to a certain power.

It is here seen how important it is to know the height of the centre of gravity of a ship: the situations of the centres of gravity are calculated and the results given.

All the calculations for finding the moments of the sails are inserted, also their effect on the inclination of a ship when close-hauled, both in action with an enemy and not in action. See Table No. 30. In Table No. 31 is inserted the necessary distance between the centre of gravity of the ship and the metacentre, in order that the ship may possess a proper moment of stability. An example is given of the calculations for finding how much the breadth of a ship must be increased or diminished to preserve the necessary distance between these two centres.

In all the calculations, $\int_3 y^3 dx$ is taken to the outside of the timbers, which properly should have been taken to the outside of the exterior plank, by which the height of the metacentre of a 74-

gun ship would be increased about $\frac{1}{4}$ of a foot; and as this increase of height is in proportion to the magnitude of the ship, it must not be considered as an error, as all the ships are in the same proportion a little stiffer than is shown in the calculations.

Chap. XII. On the lengths of the masts and yards, which are calculated for all the ships, and inserted in Table No. 32, and on other things which ought to be considered in connexion with the rigging.

Chap. XIII. To construct the drawings of a ship, without regard to the relaxation-lines.

When the displacement, the length of the upper water-line, and the breadth of the ⊕ section, and its depth from the upper water-line to the keel, are determined for a ship, with the situation intended for the centre of gravity of the displacement in respect to the length of the upper water-line; a very easy and certain method is given, which determines, 1. the area of the ⊕ section; 2. the area of each section separately, both before and abaft the ⊕ section, at such stations as are considered best; 3. the situation of the ⊕ section, so that it may give the required displacement, and that its centre of gravity may be exactly in its proper situation. And as the parabola forms the principle of this method, it is called the *parabolic method of construction*: not because this curve gives a ship certain qualities, but because it affords a facility in obtaining in a more easy manner what is required.

To show which method is the better, whether the former, which depends on the relaxation-lines, or the latter, the same ship is constructed by the latter method which had been constructed by the former method; and all the calculations relating to it are inserted in Table No. 33; and in Table No. 34 the calculations of all the sections of the five line-of-battle ships are given, according to which the drawings are made.

At the end of section 44, the exponent n for 74-gun ships $= 2{,}524$ is given, which may be diminished to 2,5; and in the same proportion for other ships: this requires some explanation.

It is not meant that the exponent n shall be diminished directly in the same proportion for the other ships, but that another co-efficient to the quantity $t^{0{,}935}$ is afterwards obtained,

which gives the distance h, the abscissa of the line of sections; when first the new exponent n is obtained for each ship in the same manner as before.

It is also stated in what manner the draughts of the various kinds of ships which have been built may be examined, so as to judge, by comparison, of their qualities, from which much information may be collected for the improvement of the science, and the refutation of many erroneous principles previously received.

In conclusion, calculations are made of the effect of the water in opposing the course of a 74-gun ship; and it is found that this effect is about $\frac{1}{30}$ part less by the latter or parabolic method, than by the former.

As far as regards the reasoning on this subject, it may be admitted, that for line-of-battle ships, the one method may be as good, in respect to the stability and good sailing, as the other; and as lately, while this work has been in hand, an experimental trial of sailing has been made with large and small armed vessels, whose after bodies were constructed by the relaxation-lines, the results of which did not show that the vessels constructed by this method are preferable, in regard to stability and good sailing, to those constructed by the parabolic method; and as the former is very difficult, as well as troublesome when any alteration is required to be made, and as the latter, or parabolic method, is in all respects very easy, the propriety of the general adoption of this method has been confirmed.

Chap. 14. On the figure called the *accumulateur*.

The description of this figure may be found in the same treatise. By the use of this figure, the manner in which the metacentre ascends, as a ship by being lightened rises out of the water, may not only be found, but may be seen by inspection; it may also be found by calculation, and seen by inspection, when any weight is taken out of the hold or from below the lower deck, how the common centre of gravity of the ship and lading thereby rises; and how the centre of gravity rises the higher the lower the weight lay in the ship, by which the distance between the common centre of gravity and the metacentre is decreased, and in what proportion the stability of

the ship is thereby diminished. This leads to the consideration of a circumstance which must be attended to in ships of war completely fitted and armed; namely, that of those weights which are wholly expended during a voyage, as many as possible should be placed at the highest part of the lading; and that those weights, only a part of which is expended, must be stowed as low as circumstances permit, in order that at the latter part of a voyage the stability of the ship may not be so much diminished as to prevent the lower-deck guns from being used, in case it should happen to come into action with an enemy.

The same figure serves also to find the height of the centre of gravity of a ship, when in a dock which is emptied by pumping. In the demonstration only the result is inserted; but if the figure be inclined, and from G and F perpendicular lines be drawn, the result which is inserted may be obtained by the similar triangles.

Chap. XV. and XVI. On frigates.

It was proposed also to determine the proper size and form for frigates. The same order is followed, and the same two methods of construction are used; and the parabolic method of construction is adopted for the same reason, and on the same principles, for frigates and smaller armed ships, as well as for all other sorts of vessels, of every size, fulness, and every necessary qualification, either to sail or row, as for line-of-battle ships.

In Table No. 40, frigates of 44 guns are inserted, with a tier of 30-pounders, because these guns are not heavier than the common 24-pounders were formerly; and in the same table the number of months, M, is reckoned at $\frac{5}{8}$ of the time of provisioning.

In conclusion, as an appendix, the proportions, and a general drawing of cannon of the usual calibre of Swedish guns, are given, as it will be useful, when the drawings of ships are made, to have their dimensions. There is also a drawing of a traverse-carriage, similar to that which is to be found in the *Architectura Navalis Mercatoria*, but improved: it is also observed, that the carriage is to be made of sound and strong oak.

It must not be neglected to be mentioned at the conclusion of this introduction, that if this work should be consulted by other nations, it is necessary to know the relation between the Swedish weights and measures and their own. The following proportions give what is necessary to be known on this subject :—

10 Swedish feet =	9,14 French	10 French = 10,9409	= Swedish feet.
	9,36 Danish	10 Danish = 10,6838	
	9,74 English	10 English = 10,2669	
	10,46 Dutch	10 Dutch = 9,5602	
	10,59 Spanish	10 Spanish = 9,4429	
	9,46 Rhenish	10 Rhenish = 10,5708	

1000 Swedish lb. =	868 French	1000 French = 1152,07	= Swedish lb.
	852 Danish	1000 Danish = 1173,71	
	937 English	1000 English = 1067,24	
	861 Dutch	1000 Dutch = 1161,44	
	922 Spanish	1000 Spanish = 1084,60	

It is assumed that pure water, all over Europe, is of the same specific gravity : and as it is found that a cubic foot of such water weighs 61,5 Swedish pounds, it is easy to find its weight according to the weights and measures of other nations. For example, if it is required to find the weight of a cubic foot of fresh water in Danish weights and measures; then, $\frac{852.\,61{,}5}{9{,}36)^3} = 63{,}898$ Danish pounds; and in English weights and measures, $\frac{937.\,61{,}5}{9{,}74)^3} = 62{,}364$ English pounds; and so on.

In this manner a cubic foot of fresh water has been calculated for each of these nations, according to their respective weights and measures, which is inserted in the following table. The weight of a cubic foot of salt water is inserted underneath; the specific gravity of fresh water being to that of salt as 39 to 40.

	Swedish.	French.	Danish.	English.	Dutch.	Spanish.
Weight in lb. of a cubic foot of fresh water	61,500	69,913	63,898	62,364	46,268	47,744
Cubic ft. of salt water	63,077	71,705	65,536	63,963	47,454	48,968

When it is required to find, from the known weight of a cubic foot of fresh water in any nation, the weight of a Swedish cubic foot in Swedish weights and measures, it may be obtained from the proportions above; for example, in Denmark, $\frac{1173{,}71 . 63{,}898}{10{,}6838)^3} = 61{,}5$ Swedish pounds; and in England, $\frac{1067{,}24 . 62{,}364}{10{,}2669)^3} = 61{,}5$ Swedish pounds.

As there is an uncertainty as to the strict correctness of the different accounts of the proportions between the weights and measures of Sweden and those of other nations, it is necessary, for the trade and commerce between nations, that there should be an established long measure, square measure, and weight, by which all nations may compare their common weights and measures; but as it would not be generally agreed on, to take as a standard the weights and measures of any particular nation, it is necessary that either the length of a pendulum, which vibrates in seconds at the equator, or the $\frac{1}{100000}$ part of an equitorial degree of longitude, be taken as a general established long measure, by which the common long measures of all nations should be compared. This might be easily done by the concurrence of the academies of Europe; and the nation which instituted such measurements at the equator, must send to other nations an iron rod or staff, the length of which is equal to the $\frac{1}{100000}$ part of an equitorial degree. The following explanation shows the manner in which the long measure of each nation may be correctly compared with the standard measure.

According to the account of Professor Celcius, (see the Transactions of the Royal Society of Sciences for 1741, the last quarter,) a degree of longitude at the equator = 62672 Swedish fathoms = 376032 feet. Take the $\frac{1}{100000}$ part of it as a con-

stant long measure; then this standard long measure in Sweden = 3,76 Swedish feet.

In obtaining a standard weight for all nations, it must be expressed in their common weights. For example, in Sweden the cube of 3,76 = 53,157, is equal to the standard solid measure; the weight of such a measure of fresh water weighs 3269,16 pounds, which is the standard weight in Swedish pounds. When this weight is divided by the standard solid measure, the weight of a cubic foot of fresh water in Sweden is obtained, which is $\frac{3269,16}{53,157} = 61,5$ pounds.

When they are found in the same manner in other nations, and the results are communicated, a general table may be drawn up, which will show the true proportion of the weights and measures of each nation with the equitorial weight and measure. The weights and measures must be expressed in whole numbers and decimals. This is all which is necessary for the academies of science to direct to be done.

It must also be observed, that if it be required to express the exponential expressions given in this work, in the measures of other nations, the exponents will remain the same, but the co-efficients will be altered. In the operation, the logarithm of the denominator is multiplied by the exponent, and the product subtracted from the logarithm of the numerator, if the latter be greater, in which case the co-efficient is a multiplier; but if the product be the greater, the logarithm of the numerator is subtracted from it, when the co-efficient is a divisor. See § 10.

Contents of the Paragraphs.

8. Calculation of the provisions, water, and wood.

9. To find from these calculations the displacement.

10. To find, from the displacement, the length and breadth of a ship of the line.

11. On the construction-element (*amne*) of a ship's body.

12. On the relaxation-lines, and their application to the after part of a ship.

13. On the situation, area, &c. of the ⊕ section.

14. On the line of sections and its construction.

15. On the completion and calculations of the construction-element, which is the foundation for the other elements of all ships.

16. On the stem and sternpost.

17. The reason that the upper water-line must be the basis of a ship's construction.

18. To construct the upper water-line before the foremost ⊕ section.

19. To construct the upper water-line abaft the foremost ⊕ section.

20. To form the plan of the half-breadth lines.

21. On the circumstances which must be considered in the formation of the ⊕ section.

22. Comparison between different forms of ⊕ sections, and proof of which is the proper form.

23. To form the ⊕ section.

24. Calculations of the areas of the sections.

25. On the different circumstances which must be attended to in constructing the sections, also the results of the draughts made according to the foregoing calculations.

26. On the stations of the frames and ports for carrying on the building.

27. On the upper works of a ship and the tumbling home of the top-timbers.

28. On the top-timbers and the exterior planking of a ship's sides.

29. How the measurements must be applied in finding the relative and absolute resistance.

30. To find the resistance of the water on a 74-gun ship, with the results of the resistance on the other ships.

31. How the area of sails is determined from the resistance of a ship, and in a certain manner from its displacement, also to find thence the breadth of the lower edges of the top-sails.

32. On the importance of knowing the situation of the common centre of gravity of a ship.

33. To find the moment of the power of the sails at an inclination of 7 degrees, and thence the breadth of the lower edge of the top-sails.

34. To find how great the inclination of a ship is under sail, both in action with an enemy and not in action.

35. To find the alteration in the breadth of a ship, that it may possess a determined moment of stability.

36. Observations on the foregoing sections.

37. To find from the breadth of the top-sails, the lengths of the lower-masts, top-masts, and yards, and the proportions of all the sails.

38. Observations on the rigging, &c. of a ship.

39. Observations on the formation of the drawings of a ship, without reference to the relaxation-lines.

40. On the advantage of the parabolic method of construction.

41. To form by means of this method of construction an element, the solidity of which is equal to that of the displacement of a ship, and with the same determined area of each section.

42. To determine the situation of the ⊕ section, so that the centre of gravity of the displacement may be at a given point.

43. Calculations which serve as a foundation for forming the construction element, and to find the ordinates of the section-line and true line, also a general rule to find the distance between the common centre of gravity and the metacentre, to obtain thence a proper moment of stability.

44. On the calculations of the areas of all the sections, with the results of the drawings made according to the foregoing calculations.

45. On the object of this method of construction, and why the line of sections should be a parabola.

46. Reasons for the adoption of the parabolic method of construction.

47. Description of what is called the *accumulateur;* also

how much a ship loses in stability by the consumption of the greater part of the ammunition and provisions; and where the weights in a ship should be placed, which are consumed in a voyage, so that it may thereby lose as little as possible in stability.

48 and 49. A practical method of finding the situation of the centre of gravity of a ship, when in dock.

50. On frigates and their object, also their construction by the relaxation-lines.

51. To construct frigates by the parabolic method.

52. Confirmation of the adoption of the parabolic method of construction.

53. A table, in which is inserted every thing relating to the formation of the drawings of a considerable number of frigates and smaller armed vessels, according to the last-mentioned method of construction; also, in conclusion, some necessary observations on the subject.

CHAP. I.—*Determines the nature of the armament, &c. of those Ships which are considered fit to be placed in a line of battle, which are called Line-of-battle Ships.*

A line-of-battle ship being estimated by its effect, and this effect being produced by the number of the guns and the weight of the shot, these are the first principles in the construction of a ship; the following particulars must therefore be determined:

1. The number of guns and weight of metal of each class of ship of which a fleet is composed.
2. The usual time for which a fleet must be provisioned.
3. The height of the battery above the water.
4. The draught of water of a ship.

1. Suppose a fleet of ships of war to be composed of three divisions. Let the commander of the fleet have one ship of 110 guns; the second in command an 80-gun ship; each chief of the two other divisions one 94-gun ship, with a leading ship of 80 guns; and let the remaining ships of the fleet which compose the main body in an action, be 74 or 66-gun ships. There

are thus five classes of ships in the fleet: namely, 110, 94, 80, 74, and 66-gun ships.

As it is shown in the Introduction, that the effect of the guns is as the weight of the shot or weight of metal, it will be assumed, that the heaviest guns with which the fleet is armed are 48-pounders, and the lightest, 12-pounders; that the difference between each kind of gun and that next above or below it, is 6 pounds[1]; and that to avoid all confusion with the shot and cartridges in action, there must be a sufficiently evident difference between the weight of metal on the different decks, which difference of weight may be taken at 12 pounds.

On these premises the armament of the five classes of ships of the line is determined in the following table.

TABLE No. 1.

Guns.	110		94		80		74		66	
	No.	Weight of Metal.	No	Weight of Metal.	No.	Weight of Metal.	No.	Weight of Metal.	No.	Weight of Metal.
1st deck	30	48	30	42	30	42	28	36	26	36
2nd deck	32	36	32	30	32	24	30	24	28	24
3rd deck	30	24	32	18						
Quarter-deck and forecastle	18	12			18	12	16	12	12	12
Total..	110		94		80		74		66	

That the difference of weight of metal between the first and second tiers of guns of an 80-gun ship is 18 pounds, is for this reason: as it is intended that the effect of an 80-gun ship should be decidedly greater than that of a 74-gun ship, the difference in their effect would be too little, if all the guns were of the same weight of metal as those of a 74-gun ship; to

[1] The weight of metal of a gun generally means the weight of the shot; but in Sweden it is otherwise, as the true weight of the shot in pounds is more than ⅑ greater than the nominal weight of metal.

render them more nearly a medium between ships of 94 and 74 guns, 42-pounders are given as their armament of the lower deck.

2. In order to be able to determine the length of time for which a fleet should be provisioned, the situation of the seat of war must be considered, which is generally the Baltic and North sea, or not far distant from them; so that if it is provisioned for 6 months, it is sufficient. But as three-decked ships, in consequence of their height above water and their heavy armament, have their centre of gravity higher than two-decked ships, their proportions and form must be such, that their metacentres may be at such a height above their centres of gravity, that with a determined area of sails, they may not incline in a line of battle more than two-decked ships; and as the length and especially the breadth, together with greater or less fulness of body, determine the height of the metacentre; and as a ship of very great dimensions, is not only more expensive, but from its length more likely to be broken, it is necessary, in order that their qualities may be the same as those of two-decked ships, to diminish their magnitude: so that 94-gun ships may carry provisions for one fourth of a month, and 110-gun ships for half a month, less than two-decked ships. This deficiency in the 6 months' provisions is either divided and put on board some of the two-decked ships of the fleet, or is put on board a transport which must accompany the fleet at the beginning of a voyage.

3. The height of the battery is next to be considered, or the height which the ports of the lower deck must be above the water. This height may be determined, so that when the ship inclines 7 degrees, the lower edge of the midship port of the lower deck may be about 3½ feet above the water, on account of the dashing and rising of the waves, which height has been found quite sufficient for the safety of the ship; but for the same reason that three-decked ships are not provisioned for so long a time as two-decked ships, they will not have so great a height of battery.

4. Concerning the draught of water it is to be observed; that as ships must pass the "Grounds,"—at least two-decked ships should be able to pass them, it is necessary that their draught

of water on an even keel should not exceed 22 or 22½ feet; but three-decked ships, as well in relation to their displacement as to preserve a similarity to two-decked ships, also on account of their greater upper works, which occasion lee-way, mus necessarily be deeper; consequently they must be lightened in a suitable manner when they pass through them.

Chap. II.—*On the Displacement of a Ship, and from what it is obtained.*

5. The displacement of a ship is determined; 1, from the weight of the guns with their furniture, ammunition, and every thing relating to the armament; 2, from the weight of ballast; 3, from the weight of the crew with the provisions, water, &c. for their subsistence; and 4, from the weight of the ship itself, with the masts and yards, rigging, anchors, cables, fittings, &c.

As the first article is the foundation for the calculation of all the other weights, not only the weights of all kinds of cannon, but of all their furniture and ammunition, required for a complete artillery, are inserted in the following table: the total weight being given for one gun of each kind.

Table No. 2.

Weight of a Gun of each kind, with all the Furniture connected with it.

Weight of Metal.	48	42	36	30	24	18	12	8	6
Weight of a gun in skippounds, light weight	31,80	27,93	24,03	20,16	16,24	12,30	8,30	5,60	4,24
Weight of a shot, in pounds, provision weight ..	59,80	52,28	44,81	37,34	29,81	22,34	14,87	9,92	7,44
Charge of powder, in pounds, provision weight	17,16	15,07	12,98	10,87	8,75	6,65	4,65	3,40	2,44
Priming, in lod, (half ounces)	4,5	4,5	4	4	4	4	3	3	3
Wad, in pounds, provision weight	4	$3\frac{3}{4}$	$3\frac{1}{2}$	$3\frac{1}{4}$	3	$2\frac{1}{2}$	2	$1\frac{1}{2}$	1
C = weight of a gun, in pounds, provision wt...	10173	8938	7696	6451	5197	3933	2656	1792	1357
Carriage, with trucks, forelocks, iron work, &c., = $3{,}58.\, C^{\frac{2}{3}}$, in pounds, provision wt. ..	1681	1542	1395	1241	1074	892	687	528	439
1 bed	20	20	18	18	16	16	12	8	6
1 coin	5	5	5	4	3	3	2	2	2
1 tompion	7	7	6	6	5	5	4	3	3
1 crow-bar and 2 hand-spikes...............	60	56	52	48	44	44	44	44	44
1 rammer and 1 sponge	26	25	24	23	22	21	19	18	16
1 apron	16	16	15	14	12	10	8	6	5
1 breeching	131	116	102	88	75	63	52	41	36
2 breeching-tails	6	6	5	5	5	4	4	4	3
1 muzzle lashing...........................	15	14	13	12	..	..	..	..	..
1 cascable-lashing.........................	3	3	2	2	2	1	1	1	1
2 breeching-lashings	11	10	10	9	8	7	6	5	4
2 tackles	80	78	76	74	72	68	60	48	40
Greatest part of ballast, pounds	12234	10836	9419	7995	6535	5067	3555	2500	1956
75 round shot	4485	3921	3361	2800	2236	1676	1115	744	558
5 bar-shot, and 8 charges of case-shot	779	680	583	487	388	291	193	129	98
75 charges of powder	1287	1130	974	815	656	499	349	255	183
80 primings	11	11	10	10	10	10	8	8	8
80 wads	320	300	280	260	240	200	160	120	80
Total, in pounds, provision weight	19116	16878	14627	12367	10065	7743	5380	3756	2883
Total, in cubic feet of water of 63 pounds	303,43	267,90	232,17	196,30	159,76	122,90	85,40	59,62	45,76

Table No. 3.

Calculations, according to the foregoing Table, for each Ship, of each article separately, in cubic feet of Water.

	Weight of Metal.	Number	Guns.	Carriages.	Furniture.	All the shot.	Powder	Wads.	Total in cubic feet.
110	48	30	4844	800,5	181,0	2506,7	618,1	152,4	
	36	32	3909	708,6	166,6	2003,3	500,3	142,2	
	24	30	2475	511,4	125,7	1249,5	317,1	114,3	
	12	18	759	196,3	60,6	373,7	102,1	45,7	
			11987	2216,8	533,9	6133,2	1537,6	454,6	22863
94	42	30	4257	734,3	169,5	2191,0	543,3	142,9	
	30	32	3277	630,4	153,9	1669,6	419,0	132,1	
	18	32	1957	453,0	122,9	999,1	258,5	101,6	
			9491	1817,7	446,3	4859,7	1220,8	376,6	18212
80	42	30	4257	734,3	169,5	2191,0	543,3	142,9	
	24	32	2640	545,5	134,1	1332,8	338,3	121,9	
	12	18	759	196,4	60,6	373,7	102,1	45,7	
			7656	1476,2	364,2	3897,5	983,7	310,5	14688
74	36	28	3422	620,0	145,8	1752,9	437,3	124,4	
	24	30	2475	511,4	125,7	1249,5	317,1	114,3	
	12	16	675	174,5	53,8	332,2	90,7	40,6	
			6572	1305,9	325,3	3334,6	845,1	279,3	12662
66	36	26	3177	575,7	135,4	1627,7	406,1	115,6	
	24	28	2310	477,3	117,3	1166,2	296,0	106,7	
	12	12	506	130,9	40,4	249,1	68,0	30,5	
			5993	1183,9	293,1	3043,0	770,1	252,8	11536
52	30	26	2662	512,2	125,0	1170,0	293,7	92,6	
	18	26	1622	368,1	99,9	700,6	181,2	71,2	
			4284	880,3	224,9	1870,6	474,9	163,8	7898

TABLE No. 4.

Total in cubic feet of Water which relates to the Armament.

	110	94	80	74	66	52
Guns, carriages, ammunition	22863	18212	14688	12662	11536	7898
Gunner's stores, three parts of them	686	546	441	380	346	237
Total in cubic feet of water = C =	23549	18758	15129	13042	11882	8135

In this table a ship of 52 guns is inserted; all the guns being placed on two decks, having none on the quarter-deck or forecastle, it is called a double frigate. This ship must sail well, in order to make long voyages; it can, on an emergency, take its place in a line of battle, and occasionally it is used as a convoy.

On the Ballast.

6. A ship of the line must necessarily have ballast in order to preserve its qualities at the end of a long voyage, when the greater part of the provisions and ammunition is consumed; and as these weights are so considerable, that the ship may be thereby lightened, for example, a foot, so the centre of gravity of the ship and lading not only rises a foot higher above the water than it was at first, but also so much the more, as these diminished weights in the hold cause the common centre of gravity of the ship to rise higher in the ship than it was; by which the stability is diminished. It is therefore necessary, in order that this loss of stability may not be too great, to have such a quantity of ballast, that the remaining weight in the hold may not be too little in relation to the constant weight above the water; and it is this quantity of ballast which is inserted in the following table, No. 5, a less quantity of which would have been sufficient, if the ship had not had such a form that when it was lightened a foot the metacentre rose higher in the ship than it was before, when it had the full lading.

Such a ship, in case it should come into action with an

enemy, when the wind is not very high, with moderate sail set, could attack the enemy, and use, without danger, the leeward lower-deck guns; whereas, on the contrary, a ship of the usual form, that is, whose breadth diminishes immediately below the water-line, and with a flat bottom, and with more than double the quantity of ballast, could not, in an equally high wind, venture the attack. This subject will be considered further, when treating on the form of the ⊕ section.

Weight, in cubic feet of Water, at 63 pounds, of all the Furniture of the Artillery, in order to find thence the weight of the Ballast.

Weight of Metal.	48	42	36	30	24	18	12	6
All which relates to the gun and furniture, table No. 2.	194,20	172,00	149,51	126,90	103,73	80,43	56,43	31,05
25 round shot on deck	23,70	20,75	17,78	14,81	11,82	8,87	5,90	2,95
25 wads, ditto	1,59	1,49	1,39	1,29	1,19	1,00	0,79	0,40
Total in cubic feet of water....	219,49	194,24	168,68	143,00	116,74	90,30	63,12	34,40

Table No. 5.

Weight of Ballast, in cubic feet of Water, for each Ship.

	From the preceding Table.	110		94		80		74		66		52	
		Number	Cub. ft.	Number	Cub. ft.	Number	Cub. ft.	Number	Cub. ft.	Number	Cub. ft.	Number	Cub. ft.
48-pounder	219,49	30	6585	..	..	..	..	..	..	..	..	..	..
42 do.	194,24	..	..	30	5827	30	5827	..	..	..	..	..	..
36 do.	168,68	32	5398	..	..	..	..	28	4723	26	4386	..	..
30 do.	143,00	..	..	32	4576	..	..	..	..	..	..	26	3366
24 do.	116,74	30	3502	..	..	32	3726	30	3502	28	3269	..	..
18 do.	90,30	..	..	32	2890	..	..	..	..	..	..	26	2430
12 do.	63,12	18	1136	..	..	18	1136	16	1010	12	757	..	..
Total			16621		13293		10699		9235		8412		5796
+ $\frac{1}{20}$			831		..		..		..		..		..
+ $\frac{1}{40}$			..		332		..		..		..		..
Total			17452		13625		10699		9235		8412		5796
Add $\frac{1}{24}$ to make up deficiency			727		568		446		385		350		241
Total weight of ballast			18179		14193		11146		9627		8762		6037
Total in skipponds, heavy weight..			2863		2285		1755		1458		1380		951

To find the Number of the Crew.

7. Men for the service of the guns, besides a boy for each gun. A, the weight of metal; B, men for the service of a gun; C, the number of guns on one side; D, the men for the service of all the guns of each weight of metal.

TABLE No. 6.

		110		94		80		74		66		52	
A	B	C	D	C	D	C	D	C	D	C	D	C	D
48	15	15	225	..	..	..	..	..	..	..	..	..	..
42	13	..	..	15	195	15	195	..	..	..	..	..	..
36	13	16	208	..	..	..	..	14	182	13	169	..	..
30	11	..	..	16	176	..	..	..	..	..	..	13	143
24	9	15	135	..	..	16	144	15	135	14	126	..	..
18	9	..	..	16	144	..	..	..	..	..	..	13	117
12	7	9	63	..	..	9	63	8	56	6	42	..	..
Total S =			631		515		402		373		337		260

In the treatise, "Kännedom af Linie-Skepp," § 8, the number of the whole crew is determined, from which may be found the number of men to be added to those for the service of the guns, namely, the different classes of officers, the musketeers, men for working the ship in action, and for other services, and the boys, denominated altogether *the reserve;* and this will apply in the North to all greater and smaller ships of the line in this manner: if the weight, in cubic feet of water, of all which is connected with the armament, Table No. 4, = C, the number of the men which are appointed to the service of the guns, Table No. 6, = S; and the reserve = R; then for the three-decked ships, $R = 12{,}79 . \overline{S + \frac{C}{50}}^{\,0{,}48}$, and for two-decked ships, R =

$5{,}942.\overline{\frac{S+C}{50}}^{0{,}6}$. The reserve, calculated accordingly, is inserted in the following Table:—

TABLE No. 7.

	110	94	80	74	66	52
Reserve = R = ...	369	333	304	285	269	228
Men for the service of the guns, S = ...	631	515	402	373	337	260
Total of the crew...........	1000	848	706	658	606	488

8. The Table in the above-mentioned treatise, § 9, affords information respecting the weight of provisions, water, &c. Coal must be substituted for fire-wood, because the weight of coal is not more than $\frac{2}{3}$ of that of wood usually allowed[1], and does not occupy more than $\frac{1}{3}$ of the room: by which a ship can take a much greater quantity of provisions[2].

[1] As the wood which is commonly allowed for cooking is twice as much as is necessary, if properly taken care of, the quantity of coal which is inserted in Table No. 9 is quite sufficient for the whole time for which the ships are provisioned.

[2] In ships of war there is always a want of sufficient room for lodging the ship's company, and especially in frigates, in which this deficiency is the greater on account of the room occupied by the boat and galley on the main deck; if therefore necessary attention be paid, that all the room appropriated to receive the provisions, water, cables, and other articles, &c. which are to be put on board, is properly divided, it will be found, that nearly all can be stowed below the orlop deck; so that in line-of-battle ships, not only can cabins be built there for some of the officers, as is usual, but a part of the ship's company can be lodged there; but in frigates, not only all the officers, but all the ship's company can be lodged there, by which frigates may always obtain the advantage of having the main-deck clear, so that there will be no obstruction in working the guns.

Table No. 8.

Calculations of the Provisions, &c.

	Provisions for 8 men for 7 days, or 56 allowances.		Weight per cubic foot.	Weight of 56 allowances.
	pounds.	cubic ft.	pounds.	pounds.
Beef	18,00	..	..	18,00
Pork	8,00	..	..	8,00
Herrings ..	8,00	..	..	8,00
Butter	6,50	..	..	6,50
Flour......	4,00	..	..	4,00
Salt	1,75	..	..	1,75
Bread	63,00	..	25	63,00
	Kans.			
Barley	6,125	0,6125	36	22,050
Pease......	3,375	0,3375	52	17,634
Grits	0,750	0,0750	30	2,250
Brandy	1,750	..	6,1 per kan	10,675
Vinegar....	0,875	..	6,1 per kan	5,337
The tare of all provisions in casks is $\frac{1}{10}$ part				6,176
56 allowances of provisions with the tare				173,372
Hence one allowance $= \frac{173,372}{56}$				3,0959

10 kans = a cubic foot.

By an allowance is meant, what is used by one man in a day.

$1\frac{1}{3}$ kan of water is allowed daily to each man for cooking and drinking. A kan of fresh water weighs 6,1 pounds, so that the weight of an allowance of water $= \frac{4.6,1}{3} = 8,133$ pounds; and as the tare of water is 24 per cent. of the weight of the water, an allowance of water with its tare $= 8,133.1,24 = 10,085$ pounds.

The weight of an allowance of wood for cooking $= 2$ pounds, and $\frac{2}{5}$ of this weight $= 0,8$ pound, the weight of coal; according to which the coal for the whole time of provisioning is calculated. An allowance of wood for dunnage is $= 0,586$ pound, which is calculated for the same time as the water.

Table No. 9.

Every thing relating to the Provisions.

Number of guns.	Number of Months for the different articles.	Number of days at 30½ days to a month.	Complement of Crew.	Number of allowances.	Weight of an allowance in pounds.	Whole quantity in pounds.	In cub. ft. of water at 63 pounds.	Total in cub. ft. of all relating to the provisions.
110	Provisions and tare 5,4	164,70	1000	164700	3,0925	509895	8094	23439
	Water and tare ..2,7	82,35		82350	10,085	830500	13183	
	Coal 5,4	109,80		109800	0,8	87840	1396	
	Dunnage wood....2,7	82,35		82350	0,586	48257	766	
94	Provisions and tare 5,7	173,85	848	147425	3,0959	456413	7245	20978
	Water and tare ..2,85	86,925		73712	10,085	743386	11799	
	Coal 5,7	115,90		98283	0,8	78626	1248	
	Dunnage wood....2,85	86,925		73712	0,586	43195	686	
80	Provisions and tare 6,0	183,0	706	129198	3,0959	399984	6349	18390
	Water and tare....3,0	91,5		64599	10,085	651481	10341	
	Coal 6,0	122,0		86132	0,8	68905	1099	
	Dunnage wood....3,0	91,5		64599	0,586	37855	601	
74	Provisions and tare 6,0	183,0	658	120414	3,0959	372790	5917	17134
	Water and tare....3,0	91,5		60207	10,085	607188	9638	
	Coal 6,0	122,0		80276	0,8	64221	1019	
	Dunnage wood 3,0	91,5		60207	0,586	35281	560	
66	Provisions and tare 6,0	183,0	606	110898	3,0959	343329	5450	15780
	Water and tare....3,0	91,5		55449	10,085	559203	8876	
	Coal 6,0	122,0		73932	0,8	59146	939	
	Dunnage wood....3,0	91,5		55449	0,586	32493	515	
52	Provisions and tare 6,0	183,0	488	89304	3,0959	276476	4389	12706
	Water and tare....3,0	91,5		44652	10,085	450315	7148	
	Coal 6,0	122,0		59536	0,8	47629	756	
	Dunnage wood....3,0	91,5		44652	0,586	26166	413	

Table No. 10.

Gives the Weight of the Provisions and Water, &c., the Ship's Company, and all which belongs to the Defence, and the Ballast, in Cubic Feet of Water.

	110	94	80	74	66	52
Every thing relating to the provisioning, Table No. 9	23439	20978	18390	17134	15780	12706
Deduct the provisions and coal for ⅔ the[1] time of provisioning	2547	2279	1999	1861	1714	1380
Remainder of every thing relating to the provisioning	20892	18699	16391	15273	14066	11326
Weight of the crew with their stores	4000	3392	2824	2632	2424	1952
Every thing relating to the armament, Table No. 4	23549	18758	15129	13042	11882	8135
Ballast, Table No. 5	18179	14193	11146	9627	8762	6037
Total of the provisions, crew, armament, ballast = A =	66620	55042	45490	40574	37134	27450

Table No. 11.

Gives the Displacements of the Ships.

	110	94	80	74	66	52
From the foregoing Table No. 10 A =	66620	55042	45490	40574	37134	27450
Ship's hull, masts and yards, rigging, &c.[2] 1,2947 A =	86255	..	..	..	..	..
Ditto ditto 1,3309 A =	..	73255	..	..	..	..
Ditto ditto $4{,}034\ A^{0{,}8987}$ =	..	..	61910	55848	51588	39303
Total displacement, D =	152875	128297	107400	96422	88722	66753
Height of battery, § 3	6,48	6,50	6,92	6,83	6,75	6,33

[1] As all the weights in a line-of-battle ship, which are consumed during a voyage, are situated below the water-line, and contribute to the stability, it follows, that when a part of these weights is consumed, the stability is diminished; thus the stability is greatest at the commencement, and least at the conclusion of a voyage; and as it seldom happens that immediately on the commencement of a voyage, hostilities take place between two fleets, it has been considered right, that all the calculations which respect the stability, should be in relation to the state of a ship, at the end of about ⅔ part of the duration of the voyage, and it is this water-line which is drawn on the draught, from which the masting is determined.

[2] The whole weight of the ship itself, together with the masts and yards, rigging, anchors and cables, &c. and the master's and carpenter's stores, are calculated for a larger and a smaller ship of the line, from which the expressions which are inserted are deduced.

Thus the displacements of ships are at length obtained, from which their dimensions, the length, breadth, and depth, must be found; and as ships are propelled forward by sails, the size of the sails, or their area, greatly influences the dimensions and form of ships: thus a ship together with its sails must be considered as one machine, whose dimensions and form are required to be found. (See the Introduction.) Hence it appears, that the dimensions and form of a line-of-battle ship cannot be determined in any other method, than by an investigation of ships which are already built, and by approximation, in ultimately obtaining what is sought.

The drawings in this work are made agreeably to these principles and the before-mentioned methods, according to which general rules will be given, by which the drawings of all classes of ships of the line may be constructed in a more methodical manner than has been hitherto adopted, and with greater certainty.

Chap. III.—*Method by which the Length and Breadth of a Ship should be found.*

The method of determining the length of a ship by the number of ports, the space between them, and the distance forward and abaft to the stem and the sternpost, is erroneous; the product of the number of guns into their weight, principally determines the displacement, consequently the displacement must determine the length, which may be seen from what follows; and it will be found, that the length so determined, will agree with the determined number of guns on the lower deck. If it should happen, that the length is considered to be too great for the number of ports, it is on this account: that as the sum of the weights of the guns is given and constant, it follows, that if each gun is of a greater weight of metal, the number is smaller; and if each gun is of a less weight of metal, the number is greater; but the length of the ship is nevertheless the same.

As it is the object to construct these ships, and especially their after bodies, according to the expression obtained for the effect of the water; and in order that the diagonals of the after

bodies may as nearly as possible, agree with the direction of the[1] relaxation-lines; it only becomes necessary in the first place, to form general rules from the given displacement, for finding the length l, which is called the construction-water-line, and the breadth of the ship B, which is the greatest breadth at the water-line, for all ships of the line; in obtaining which, the method which I have called in reference to its object the exponential calculation, has been found to be best adapted.

Draughts of the five classes of ships of the line have been constructed with exactness and great care, in conformity with what was recommended in the introduction, and the necessary calculations have been made and verified by repeated operations, until the ships possessed their present size, stability, resistance, &c. In the following table, the length l, and breadth B, have been determined accordingly.

TABLE No. 12.

	110	94	60
Displacement, D =	152875	128297	88722
Length, l ...... =	207,59	196,65	175,48
Breadth, B .... =	56,27	53,32	48,46

In finding the length, l, from the displacement, for all ships the line, the ships of 94 and 66 guns have been used. Put therefore 128297=([2])D, and $88722=D$, also 196,65=l, and $175,48=l$.

[1] It was found by physical experiments, made in the year 1794, (see the transactions of the Royal Academy of Sciences, first quarter for the year 1795, § 15,) that the effect of the water on the after end of a body in opposing its progress, is a minimum, when the surface of the body makes an angle of 13° 17′ with its middle line; the line which this angle makes with the middle line of the ship is called the relaxation-line.

[2] When a general rule is to be found for a larger and a smaller ship, Roman letters are used for the larger ship, and Italic for the smaller ship.

As the exponential method is to be used;
$D^v : D^v :: 1 : l$; hence

$$\text{the exponent } v = \frac{\text{log. } 1 - \text{log. } l}{\text{log. D} - \text{log. } D} = \frac{\text{log. } 196{,}65 - \text{log. } 175{,}48}{\text{log. } 128297 - \text{log. } 88722}$$

196,65....	2,2936940	128297....	5,1082165
175,48....	2,2442276	88722....	4,9480313
	0,0494664		0,1601852

$$\frac{0{,}0494664}{0{,}1601852} = 0{,}3088 = v$$

	2,2936940	
5,1082165. 0,3088=	1,5774172	
	0,7162768....	5,2033=the co-efficient
	2,2442276	
4,9480313. 0,3088=	1,5279520....	5,2033=the co-efficient

These two co-efficients are the same, although they were not correctly calculated before.

Thus the length $l = 5{,}2033\ D^{0{,}3088}$, is [1] obtained for all the line-of-battle ships.

To find the breadth B from the length l for three-decked ships, the same method is used. Thus the exponent for 110 and 94-gun ships, $v = \frac{\text{log. } 56{,}27 - \text{log. } 53{,}32}{\text{log. } 207{,}59 - \text{log. } 196{,}65} = 0{,}9947$, and as the co-efficient is found to be a divisor=3,5863, the breadth B, for all three-decked ships of the line $= \frac{l^{0{,}9947}}{3{,}5863}$.

[1] To obtain the proportion of the length directly from the displacement, is not considered mathemetically correct for this reason: that if one thing is to be compared with another, the two quantities must be homogeneous or of the same kind, namely, a solid with a solid, a plane with a plane, and a line with a line; but it will be found, that this method of obtaining the length, agrees with the principle. When a length is compared with a solid body, the comparison is with the cube root of the body; and as it is the cube root when the exponent is $\frac{1}{3}$, it follows, that when the exponent is less than $\frac{1}{3}$, as in the case of the exponent being=0,3088, the less ship has a greater length in proportion to its displacement than the larger ship; and when the exponent is greater than $\frac{1}{3}$, the less ship has on the contrary a less length in proportion to its displacement than the larger ship. Likewise when a plane is compared with a solid, it is with the square o fthe cube root that the comparison is made, the exponent of which is $\frac{2}{3}$; consequently, when the exponent is less than $\frac{2}{3}$, the area of the plane is greater in proportion to the solid than when the exponent is greater.

To find the breadth B from the length l for two-decked ships. The exponent v, of ships of 94 and 66 guns, $= \frac{\text{log. } 53,32 - \text{log. } 48,46}{\text{log. } 196,65 - \text{log. } 175,48} = 0,8391$, and as the co-efficient is a divisor $= 1,5767$, the breadth B for all two-decked ships of the line $= \frac{l,^{0,8391}}{1,5767}$; according to which the following table is calculated.

Table No. 13.

	110	94	80	74	66	52
Displacement, D =	152875	128297	107400	96422	88722	66753
Length, l ...... =	207,59	196,65	186,15	180,05	175,48	160,72
Breadth, B .... =	56,27	53,32	50,92	49,51	48,46	45,01

11. As in this treatise, the intended form of a ship's body cannot be immediately given, without first preparing from the displacement the construction-element, and forming the ship's body from this element, the method of obtaining it will be here explained.

The form of this element, whose solidity is to be equal to the displacement of the ship, must be such, that its upper plane shall form a rectangle, the length of which is equal to the length of the water-line, the breadth equal to the greatest breadth at the water-line, and the depth equal to the area of the ⊕ section divided by the breadth. The vertical form of this element has a very great resemblance to a segment of a circle; but the curve-line which forms this segment, must be such that when its vertical ordinates are multiplied by the breadth of the rectangle, it will give the areas of the plane sections equal to the areas of the vertical sections of the ship at the corresponding stations; also that when the greatest depth of this element is multiplied by the breadth of the rectangle, it will give the area of the ⊕ section: which is illustrated by what follows.

Let Fig. 46 be such an element or body. Let AB be, $= l$, equal to the length of the upper plane, and put its breadth $= B$,

As the area of the greatest section $= \oplus$, the depth EF of the body at that station will be $= \frac{\oplus}{B} = k$. Put the displacement or known solidity of the body $= D$. Let the form of the bottom, or the curve-line AFB, which represents it, be a parabola with its vertex in F, the place of the greatest section; the abscissa EF is then $= k$, and $l =$ to the length of both the ordinates EA+EB. Let its equation be $p\,x = y^n$, then the area of the whole parabolic space ABFA is $= \frac{D}{B} = M$, and the exponent of the parabola $= \frac{M}{lk - M}$; by which the parabola is constructed, and from which the co-ordinates, a, b, c are known; when these are multiplied by the constant breadth, B, the areas of the sections at the corresponding stations are obtained.

(*To be continued in the next Number.*)

Art. X.—*Description of an Improved Bow for Ships of War. By* R. F. S. Blake, Esq., Assistant Master-Shipwright of His Majesty's Dock-yard at Portsmouth.

(*To the Editors of Papers on Naval Architecture.*)

Gentlemen,

I beg to offer for insertion in your valuable work, a few remarks on a newly-constructed bow, which I have lately proposed for ships of war. The object I have in view, is to render the armament of our ships of war as efficient as possible, an object which has lately particularly engaged the attention of naval officers and naval constructors.

The experience of the last war clearly showed the necessity of the better fortifying the extremes of our ships; the sterns have of late years been well fortified, the bows alone have remained imperfectly and inadequately armed. Numerous are the cases in which our naval commanders have deplored this defect: in coming up with an enemy after a chase, they have frequently been obliged to alter their course even to bring a single gun to bear from the lower or main deck; the ship

chased, has the power of taking advantage of this defect in the choice of her position; and in addition to all the disadvantages of a badly-fortified bow hitherto experienced, the sterns of an enemy's ships will undoubtedly in a future war, be as completely fortified as those of our ships now are, which renders it imperative that the bows of our men-of-war should present to them an equal force. It is to little purpose that the sailing qualities of our ships should be improved, and particularly that their velocity should be increased, if the essential quality of employing their artillery to advantage be wanting.

To obtain this important object, I delineated what I conceived to be the most complete form for a battery at this extremity of the ship, not only to employ the greatest number of guns (at least equal both in number and force to those of the stern) conveniently in a line with the keel, or in direct chase, but that the guns might be used with equal ease in oblique firing or quartering, as it is called in marine gunnery. After many trials, I trust I have succeeded in accomplishing this object; and I have the satisfaction of having my conviction strengthened by the opinion of many eminent scientific and practical men, who have expressed themselves decidedly in its favour in every point of view. In carrying this plan into effect on His Majesty's ship Vindictive, under repair in this dock-yard, I have been able to realize all the advantages I expected in this class of ships; and it is, I believe, generally considered, without injury to the symmetry and general appearance of the bow.

Fig. 47, will illustrate the principle on which the bow is formed: suppose it to represent the plan of the fore part of a ship's deck; *a b* is the fore part of the bow which is inclined to the middle line (or direction of the keel) of the ship *ah* at an angle of 60 degrees; then by the guns being trained to an angle of 30 degrees with the plane of the bow, at which they will conveniently project from the ship's side, they will point in a fore and aft direction, *cc*. When these guns are required to quarter, by their being trained aft to the same angle of 30 degrees with the plane of the bow, their direction *dd* will be parallel to the direction *ee* of the broadside guns, trained to the same angle of 30 degrees with the ship's side. The chase guns can therefore be used equally well in quartering in support of the broadside guns, as they can in a fore and aft

direction. Now it is well known in practice, that guns can be trained safely to 35 or 37 degrees with the planes of the ports, so that there will be an allowance of 5 degress or more, by which the fire of the bow guns on one side may cross the fire of those of the other, and the fire of the bow guns cross the fire of the broadside guns; and it admits also for a variation in the course. The bow is readily formed from these lines by drawing a curved line *ggg*, to which the lines *ba* and *bf* are tangents.

This principle may be carried into effect with perfect ease in the construction of a ship's bow. From the seat of water downwards, the body remains unaltered, and the bow gradually assimilates upwards with the required form at the lower deck, or about eight feet above the water, which is continued upwards to the forecastle with but little alteration. Fig. 48 represents a comparative view of the proposed bow, and a bow of the usual form at the lower deck of an eighty-gun ship; the line *abc* shows the form of the proposed bow, the part *ab* being straight and inclined at an angle of about 60 degrees with the line of the keel; and the dotted line *def* shows the usual form.

The increase of force which may be obtained by the proposed plan in the different classes of our ships, may be seen by the following comparison with the present force of our bows.

No. of guns.	Proposed plan.	Present force.
A three-decked ship, or first-rate, can employ in the direction of the keel . .	12	4
For quartering on each side	7	4
A two-decked ship, comprising second and third rates, can employ in the direction of the keel	8	4
For quartering on each side	4	3
A frigate of the large class can employ in the direction of the keel . . .	6	2
For quartering on each side	3	2
All other classes of frigates can employ in the direction of the keel . . .	4	2
For quartering on each side	2	2
Corvettes and brigs	2	none
For quartering on each side	1	1

I think it proper to remark on the description of force given above, that in the first-rate, I have in the arrangement of her ports given on the lower deck an extra bow port on each side, which may be used conveniently for quartering, or as a broadside gun, and may be found particularly useful when the guns may be required to train before the beam, on which occasion the after gun from the rounding in of the body aft, may be rendered useless.

The increased weight of metal on this plan in direct chase, is in some cases three times, and in the least advantageous, upwards of twice the present weight of metal.

If the difference in the resistance of the air on the two bows should not be considered too trifling to be mentioned, it may be observed, that its effect will be diminished by the increased obliquity of the fore part of the form proposed. It may also be remarked, that in pitching, a ship's course will be less impeded by the part of the bow above the water being more oblique to the direction of the force.

In conclusion I beg to remark, without reverting to the good which might have been derived in casualties from a well-armed bow in former wars, such as entering harbours, attacking gun-boats, and for defence when a ship is stationary in a tides-way, or aground, &c., that I cannot but anticipate what may happen in future,—when it is generally conjectured, in the event of hostilities, a novel and more active mode of warfare will be adopted by all, by the introduction of steam navigation into naval warfare. The increased facilities it will afford to the rapid movements of armed vessels, will render every improvement that can be made in the means of attack and defence in our ships of war the more necessary. The advantages which will result from the introduction of the proposed form of our ships, will I trust be found highly important in this respect.

I remain, Gentlemen,

Your obedient servant,

R. F. S. Blake.

Portsmouth Dock-yard, 14*th May,* 1830.

Art. XI.—*Method of finding the Centres of Gravity of the Load-water and Midship Sections, and the Centre of Gravity of the Displacement.*

No. 2. In the last number of this work, we gave the method of calculating the displacement of a ship; and in the operation, the areas of the load-water and midship sections were found. We shall now proceed to find the centres of gravity of the load-water and midship sections, and the centre of gravity of the displacement.

If any body is supposed to consist of an indefinite number of corpuscles, the sum of each corpuscle multiplied by its distance from any given plane, divided by the sum of the corpuscles, gives the distance of the centre of gravity of the body from that plane.

The rules given in Art. I, in the last number for approximating to the areas of plane surfaces and the contents of solids, are equally applicable to the determination of their centres of gravity. If y represent any ordinate of a curve, perpendicular to its abscissa x, measured from its initial point, $\int ydx$ will be the area contained between the ordinate, abscissa, and curve; and $\int yxdx$ will be the product of the ordinates multiplied by the differential dx, and by the distance x. Therefore the distance of the centre of gravity of this curvilinear space from the initial point, will be $\frac{\int yxdx}{\int ydx}$. The situation of the centre of gravity of a solid body is found in a similar manner.

Every transverse ordinate of the load-water section being bisected by the longitudinal line passing through the middle of the stem and sternpost, the parts on each side of this line will balance each other, and therefore the centre of gravity of this section will be in this line; it is thus necessary only to find its situation longitudinally. The centre of gravity of the midship section being in the vertical line passing through the middle of the keel, it is necessary only to find its situation vertically. For a similar reason, the centre of gravity of the displacement being always in the longitudinal vertical section passing through the middle line of the load-water section and the middle line of the keel, it is necessary only to find the vertical and longitudinal

sections in which the centre of gravity is situated; the intersection of these three planes is the situation of the centre of gravity of displacement.

In finding the centre of gravity of any curvilinear space, by means of either of the above-mentioned rules of approximation, each ordinate is multiplied by its perpendicular distance from a given line, usually a line taken near one of its extremities, and these products are used as ordinates, and the operation is performed in the same manner as for finding the area; the area of the part of the curvilinear space on the opposite side of the given line from which the perpendicular distances of the ordinates are measured, is multiplied by the distance of its centre of gravity from that line, determined by a separate operation, and the product subtracted from the result obtained by the products of the ordinates into their distances, by the rule of approximation. The remainder divided by the area of the curvilinear space, gives the distance of its centre of gravity from the given line. In this manner the centres of gravity of the load-water and midship sections are found.

The centre of gravity of the displacement is found in the same manner: in obtaining the depth of its centre of gravity below the load-water section, each successive horizontal section is multiplied by its perpendicular distance below the load-water section, and the products are used as ordinates in one of the rules; to the result is added the product of the part of the displacement below the lowest horizontal section multiplied into the distance of its centre of gravity from the load-water section; the result divided by the total volume displaced, gives the distance of its centre of gravity below the load-water section. The situation of the centre of gravity of the displacement longitudinally is obtained in a similar manner, by multiplying the area of each vertical section by its distance from one of the extreme vertical sections, as No. 1, fig. 2, and proceeding as before; the result divided by the total volume displaced, gives the distance of its centre of gravity from this section.

Instead of multiplying each ordinate by its perpendicular distance from the given line or plane, it is more convenient to multiply the successive ordinates by 1, 2, 3, 4, &c., and the sum of their products by the common distance between them.

The following calculations determine the situations of the centres of gravity of the load-water and midship sections, and of the displacement longitudinally and vertically, of His Majesty's ship Volage.

To find the Centre of Gravity of the Load-water Section.

The ordinates used are given in the first horizontal line of the table, pages 12 and 13; the common distance between them is 5 feet.

1.... 3,85	×	0	=	0,00
2.... 9,75	×	1	=	9,75
3 ...12,05	×	2	=	24,10
4....13,50	×	3	=	40,50
5....14,30	×	4	=	57,20
6....14,92	×	5	=	74,60
7....15,50	×	6	=	93,00
8....15,72	×	7	=	110,04
9....15,90	×	8	=	127,20
10....16,04	×	9	=	144,36
11....16,07	×	10	=	160,70
12....16,10	×	11	=	177,10
13....16,10	×	12	=	193,20
14....16,10	×	13	=	209,30
15....16,10	×	14	=	225,40
16....16,10	×	15	=	241,50
17....16,05	×	16	=	256,80
18....16,00	×	17	=	272,00
19....15,80	×	18	=	284,40
20....15,50	×	19	=	294,50
21....14,60	×	20	=	292,00
22....12,25	×	21	=	257,25

1.. 0,00	4.. 40,50	2.. 9,75
22..257,25	7.. 93,00	3.. 24,10
257,25	10..144,36	5.. 57,20
	13..193,20	6.. 74,60
	16..241,50	8..110,04
	19..284,40	9..127,20
	996,96	11..160,70
	2	12..177,10
	1993,92	14..209,30
	257,25	15..225,40
	6872,07	17..256,80
	9123,24	18..272,00
	15	20..294,50
	4561620	21..292,00
	912324	2290,69
	8)136848,60	3
	17106,07	6872,07
	5	

85530,35 middle moment.
6857,82 after moment.

92388,17
4,33 fore moment.

Half-area of load-water section..1624,61)92383,84(56,86
812305

1115334
974766

1405680
1299688

.1059920
974766

..85154

To find the After Moment.

63,381 area abaft section 22.
108.2 { distance of its centre of gravity from section 1.

126762
507048
633810

6857,8242 after moment.

To find the Fore Moment.

6,18 area before section 1.
–,7 { distance of its centre of gravity from section 1.

–4,326 fore moment.

The centre of gravity of the load-water section is thus found to be 56,86 ft. abaft section 1, or 1,15 feet before the middle of the length of the load-water line: the length of the load-water line being measured from the after part of the rabbet of the sternpost to the fore part of the rabbet of the stem.

To find the Centre of Gravity of the Midship Section.

The ordinates used in the following calculation, are given in the last vertical column of the table, page 12; the common distance between them is 1 foot.

1....16,10	×	0	=	0,00
2....16,06	×	1	=	16,06
3....15,95	×	2	=	31,90
4....15,75	×	3	=	47,25
5....15,48	×	4	=	61,92
6....14,98	×	5	=	74,90
7....14,22	×	6	=	85,32
8....13,18	×	7	=	92,26
9....11,80	×	8	=	94,40
10....10,05	×	9	=	90,45
11.... 7,96	×	10	=	79,60
12.... 5,45	×	11	=	59,95
13.... 2,95	×	12	=	35,40

```
  1.. 0,00            4..47,25               2..16,06
 13..35,40            7..85,32               3..31,90
 ---------           10..90,45               5..61,92
     35,40           ---------               6..74,90
                       223,02                8..92,26
                            2                9..94,40
                     ---------              11..79,60
                       446,04               12..59,95
                        35,40               ---------
                      1532,97                  510,99
                     ---------                      3
                      2014,41               ---------
                            3                 1532,97
                     ---------
                    8)6043,23
                     ---------
                       755,40 upper moment.
                        47,91 lower moment.
                     ---------
               154,25)803,31(5,2
                       77125
                      -------
                       .32060
                        30850
                       ------
                        .1210
                       ------
```

To find the Moment below the Horizontal Ordinate 13.

```
 3,63 area below horizontal ordinate 13.
13,2  distance of its centre of gravity below horizontal ordinate 13.
-----
  726
 1089
 363
------
47,916 lower moment.
```

The distance of the centre of gravity of the midship section below the load-water line is thus found to be 5,2 feet.

To find the Centre of Gravity of the Displacement Longitudinally.

The half-areas of the vertical sections used in the following calculation are given in the lowest horizontal line of the table, pages 12 and 13; the common distance between them is 5 feet.

1....	17,40	×	0	=	00,00
2....	40,98	×	1	=	40,98
3....	63,36	×	2	=	126,72
4....	83,17	×	3	=	249,51
5....	102,87	×	4	=	411,48
6....	115,29	×	5	=	576,45
7....	127,32	×	6	=	763,92
8....	135,82	×	7	=	950,74
9....	142,73	×	8	=	1141,84
10....	147,80	×	9	=	1330,20
11....	151,60	×	10	=	1516,00
12....	153,79	×	11	=	1691,69
13....	154,25	×	12	=	1851,00
14....	153,56	×	13	=	1996,28
15....	151,88	×	14	=	2126,32
16....	150,46	×	15	=	2256,90
17....	144,34	×	16	=	2309,44
18....	137,82	×	17	=	2342,94
19....	128,22	×	18	=	2307,96
20....	112,46	×	19	=	2136,74
21....	93,38	×	20	=	1867,60
22....	63,49	×	21	=	1333,29

1.. 0,00	4.. 249,51	2.. 40,98
22..1333,29	7.. 763,92	3.. 126,72
	10..1330,20	5.. 411,48
1333,29	13..1851,00	6.. 576,45
	16..2256,90	8.. 950,74
	19..2307,96	9..1141,84
		11..1516,00
	8759,49	12..1691,69
	2	14..1996,28
		15..2126,32
	17518,98	17..2309,44
	1333,29	18..2342,94
	57705,66	20..2136,74
		21..1867,60
	76557,93	
	15	19235,22
		3
	38278965	
	7655793	57705,66
	8)1148368,95	
	143546,12	
	5	
	717730,60 middle moment.	
	27795,20 after moment.	
	745525,80	
	36,97 fore moment.	
Half of the displacement in cubic feet	12984,87)745488,83(57,41	
	6492435	
	.9624533	
	9089409	
	.5351240	
	5193948	
	.1572920	
	1298487	
	.274433	

To find the After Moment.

258,56 solid abaft section 22.
107,5 { distance of its centre of gravity from section 1.

129280
180992
258560

27795200 after moment.

To find the Fore Moment.

52,81 solid before section 1.
–,7 { distance of its centre of gravity from section 1.

–36,967 fore moment.

The situation of the centre of gravity of the displacement longitudinally, is thus found to be 57,41 feet abaft section 1, or 1,75 before the middle of the length of the load-water line, measured as before mentioned.

To find the Distance of the Centre of Gravity of the Displacement below the Load-water Section.

The half-areas of the horizontal sections used in the following calculations, are given in the last column of the table, page 13; the common distance between them is 1 foot.

1....1624,61	×	0	=	0,00
2....1572,08	×	1	=	1572,08
3....1509,51	×	2	=	3019,02
4....1435,45	×	3	=	4306,35
5....1347,63	×	4	=	5390,52
6....1246,38	×	5	=	6231,90
7....1132,34	×	6	=	6794,04
8....1004,44	×	7	=	7031,08
9.... 865,90	×	8	=	6927,20
10.... 709,66	×	9	=	6386,94
11.... 544,69	×	10	=	5446,90
12.... 366,88	×	11	=	4035,68
13.... 211,74	×	12	=	2540,88

1.. 0,00
13..2540,88
2540,88

4..4306,35
7..6794,04
10..6386,94
17487,33
2
34974,66
2540,88
118963,14
156478,68
3
8)469436,04
58679,50 upper moment.
4034,10 lower moment.

2..1572,08
3..3019,02
5..5390,52
6..6231,90
8..7031,08
9..6927,20
11..5446,90
12..4035,68
39654,38
3
118963,14

Half-area of the load-water section .... } 12984,87)62713,60(4,829
5193948
10774120
10387896
..3862240
2596974
12652660
11686383
..966277

To Find the Moment below Horizontal Section 13.

316,4 solid below horizontal section 13.
12,75 distance of its centre of gravity below horizontal section 13.
15820
22148
6328
3164
4034,100 lower moment.

The distance of the centre of gravity of the displacement below the load-water section is thus found to be 4,829 feet.

Recapitulation of the results of the preceding calculations, of the different elements of his Majesty's ship Volage.

	Feet.
Distance of the centre of gravity of the load-water section before the middle of its length, measured from the after part of the rabbet of the sternpost to the fore part of the rabbet of the stem - - - -	1,15
Distance of the centre of gravity of the midship section below the load-water line - - - - -	5,2
Distance of the centre of gravity of the displacement before the middle of the length of the load-water section, measured as before - - - - - -	1,75
Distance of the centre of gravity of the displacement below the load-water section - - - -	4,829

Art. XII.—*Observations on the Forces which act on a Ship when in Motion, as they affect the Deviation of her Course from the line of the Keel.*

In Articles 16 and 29, Vol. II., the laws which govern the mutual action of the wind and water on a ship, when she is in motion, have been explained, principally as they affect her equilibrium round a vertical or an horizontal axis of rotation; in order, by pointing out the various states of equilibrium which result between the action of the wind on the sails, and the water on the hull, to show the effects which may be produced on the qualities of the ship by modifications in these equilibrio; either by the use of the helm, by alterations in the trim of the ship, in the quantity of the sail set, or in the disposition of that quantity; that in the various changes which may take place in the state of the wind or of the sea, the qualities of the vessel may either experience the least possible injurious effect, or the greatest possible degree of benefit, according as the tendency of the change may be injurious or advantageous. In pursuing this train of reasoning, it has also been the endeavour to explain the methods by which the principles which govern the making action of these forces, may be most easily applied to such observations on the various effects which may result, or

the phenomena which may occur, as may lead to correct conclusions being formed of the powers and qualities of the ship, and to the best means of rendering those qualities most easily available. And it has been shown, that by means of observations and experiments made according to the principles which have been advanced, the commander of a vessel would not only acquire such a knowledge of her qualities, that he would be enabled to derive a maximum of advantage from them, that is, as far as the means in his power would admit, or, in other words, as far as the fitness of the proportions and positions of the masts and yards, or the trim of the vessel, &c. &c. would admit, but, he could also obtain sufficient data to enable the naval architect to judge correctly of the adequacy or inadequacy of those means, to the wants or capacities of the vessel; and to effect such alterations, if necessary, as would tend to improve those means, and still further render the properties of the vessel available.

It is evident that whatever may be the exigencies of the service required of a vessel, there must always be some maximum of efficiency with reference to those services, which is to be arrived at by a judicious combination of the powers of the vessel with the means which call them into action. The distinguishing division of the characteristics of the qualities required in vessels are mainly those peculiar to burden, and those peculiar to velocity. In men-of-war, in almost all circumstances, it is a combination of the two, which is the desideratum: and it is not sufficient that a vessel should be only capable of great velocity in direct courses, or when the propelling force acts in the direction of the keel, for it is, in most cases, of more importance that she should be capable of great velocity when acted upon by a force in a direction oblique to her length; and, at the same time, that the deviation of her course from this line should be the least possible.

The principles on which this deviation of the course of a ship from the line of her keel, or the angle of lee-way depends, will now be explained; and the causes will be shown which occasion the actual results of observations on ships, to differ from the theoretic principles which have been advanced by the writers on this subject: and such methods will be suggested, for making further observations, in reference to these qualities, as may be

desirable, with a view to collect data to supply the deficiencies resulting to the theory, from the imperfect state of our knowledge respecting the resistances of fluids, particularly as they affect the oblique passage of a ship through the water.

Whatever may be the angle which the direction of the wind makes with the plane of the sails, the only effective force of the wind on the sail, is that part of the whole force which can be resolved into a direction perpendicular to the surface of the sail; therefore, whatever may be the whole force of the wind, its effective force will vary as the sine of the angle which the direction of the wind makes with the sail: and as the velocity of the ship is in proportion to the effective force of the wind, it will also, all things else remaining the same, vary as the sine of this angle. Now, as, when the ship is under sail, the direction of its motion should coincide with the middle line, that is, with the direction of the keel, as the plane of resistance is less when the ship moves in that direction than it is when the line of motion cuts the ship obliquely, all that part of the force of the wind which acts in any other direction than that of the keel, must be disadvantageous to her progress, as tending to force her in a direction in which she will meet with an increased resistance from the water. From what has been said above, this injurious tendency must necessarily occur in every circumstance of the action of the wind on the sails of a ship, excepting in that under which the trim of the sails is at right angles to the middle line of the ship, as under all other circumstances the force of the wind on the sail may be resolved into two, both of which will have effect on the ship, the one acting perpendicular, and the other parallel, to the middle line: or, if we suppose AB Fig. 49, to be the middle line of a ship, and CD the direction of the yard, making with AB, the angle DEB, less than a right angle; and suppose FE to represent the quantity and direction of the force of the wind; from E and F draw EG perpendicular, and FG parallel to DC; and from G draw GH perpendicular to AB; then GE will represent the effective force of the wind on the sail, and GH and HE will be respectively equal to the parts of that force employed in propelling the vessel in a lateral and in a direct course. If CD, the direction of the yard, were perpendicular to AB, the line of the keel, the lateral effort of the

wind, or the force GH, would be lost, and have no effect on the ship: but when CD is oblique to AB, whatever may be the quantity or direction of the force FE of the wind with respect to AB, it may be resolved into two forces, both of which will be effective on the ship. As long as DEB, the angle formed by the direction of the yard with the line of the keel, remains the same, its complement, the angle GEH, will remain the same, and as GHE is a right angle, the triangle GEH will remain similar to itself, and the proportion between GH and HE will be invariable, and, therefore, the effort to cause the deviation of the course from the line of the keel, or the action of the force GH, will be in invariable proportion to the force acting to propel the vessel along that line, or the force HE; and, as we know from what has been before said, that the forces GH and HE must be respectively equal to, and opposed by, the lateral and direct resistances of the water acting in the directions HG and EH, the motion of the ship must be along some line *ab*, such that the equilibrium between these forces may be maintained. This is the principle on which the deviation of the course of the ship from the line of the direction of the keel depends.

The angle of lee-way is determined as follows:—Suppose the direct and lateral resistances of the water to the passage of the vessel to be respectively R and r, and the surfaces respectively opposed to these resistances to be d and e, and the angle DEB, which the sail makes with the line of the keel to be c; then if the angle of lee-way be supposed to be x, we have

$$\mathrm{R} : r :: d.\cos.^2 x : e.\sin.^2 x$$

$$\frac{\mathrm{R}}{r} = \frac{d.\cos.^2 x}{e.\sin.^2 x} = \frac{d}{e.\tan.^2 x}$$

$$\text{and } \frac{\mathrm{R}}{r} = \frac{\mathrm{EH}}{\mathrm{HG}} = \frac{\sin. c}{\cos. c} = \tan. c$$

$$\therefore \frac{d}{e.\tan.^2 x} = \tan. c;$$

$$\text{or, } \tan.^2 x = \frac{d}{e}\cot\mathrm{an}. c.$$

$$\tan. x = \sqrt{\frac{d}{e}\cot. c}$$

From this equation, also, it appears that the angle of lee-way depends wholly on the angle of inclination of the sail to the line of the keel, without in any way involving the velocity of the ship; and most writers on Naval Architecture have in this manner considered the question of the equilibrium which exists between the force of the wind, and of the resistance of the water in producing this angle. Bouguer has calculated an elaborate table of the angles of lee-way for various classes of ships, for the several degrees of inclination of the sail to the keel, from 30° to 90°; but the results which he has obtained differ essentially from those derived from observation on the actual performances of vessels.

According to the theory which has been explained, and on which Bouguer founded his calculations, the lee-way depends solely on the angle formed by the yard and the keel, and is uninfluenced by any other cause, and therefore is neither affected by the angle which the direction of the wind makes with the sail, or by the velocity of the vessel; but this is contrary to the facts elicited by the experience of the actual motion of a ship under sail. From the geometrical construction which has been given, it is evident that whatever may be the force or the direction of the wind, the proportion which GH bears to HE will increase as the angle DEB diminishes, and so far the theory agrees with experience, but it is well known to all who have observed the motion of a vessel through the water, that, without any alteration in the direction of the wind with the keel, the lee-way varies with every variation in the velocity of the vessel; and also from the same cause, the alteration in the velocity, if, all things else remaining the same, the angle formed by the direction of the wind with the keel be altered, the angle of lee-way will also experience an alteration; in fact, so greatly does the angle of lee-way depend on the velocity of the ship, that in the same vessel under similar circumstances of bracing of yards and direction of wind with the keel, with only the variation of a difference in the force of the wind, the quantity of lee-way will vary from that which occurs by the ship almost drifting in the direction of the sine of the angle of incidence of the direction of the wind on the sail, to that which would exist if her course almost coincided with the line of

her keel, or to a quantity which, in practice, would evidently be scarcely observable.

There is some difficulty in accounting for this difference between the results of theory and the facts of experience; it depends in a great measure on the imperfection of our knowledge respecting the laws of the motion of bodies in fluids, so that we are unable to estimate the circumstances of the resistance of the water on the bows and on the side of the ship. The results of the theory of resistances, when applied to oblique impulses, vary very considerably from the actual resistances as observed by experiment, more especially as the angles of incidence become more acute, this discrepancy affects the lateral resistance, or the resistance on the broad-side, more than the direct, or that experienced by the bows of the vessel, and therefore has a corresponding influence in causing the actual lee-way of a ship to differ from the theoretic result. But this is one of those difficulties arising from the imperfect state of the theory of resistances, which may be classed among those which were referred to in the early part of these observations, as requiring "only to be fully known and understood, to be, if not absolutely theoretically solved, at least from the collection of facts, from experiment, and from analogy, so far overcome, as to leave nothing to be desired." The course of these remarks will tend to show the possibility of this. Professor Robison in his excellent Treatise on Seamanship, speaking of the results deduced by Bouguer says, "that the person who should direct the operations on ship-board in conformity to the maxims deducible from M. Bouguer's propositions, would be baffled in most of his attempts, and be in danger of losing his ship. The whole proceeds on the supposed truth of that theory, which states the impulse of a fluid to be in the proportion of the square of the sine of the angle of incidence, and that its action on any small portion, such as a square foot of the sails or hull, is the same as if that portion were detached from the rest, and were exposed single and alone, to the wind and water in the same angle." * * * * "But let it be observed, that the theory is defective in one point only; and although this is a most important point, and the errors in it destroy the conclusions on the general propositions, the reasonings remain in full force, and the *modus operandi* such as is stated in the theory."

There is another cause existing to occasion the deviation which is observable in the practical results of the lee-way of a ship from the conclusions of theory, which arises from the theory's not embracing the whole of the circumstances attendant on a vessel's motion through the water. By recurring to the explanation which has been given of these circumstances, in a previous portion of this paper, some further elucidation may be afforded to the unsatisfactory result of the theory. When motion is communicated to a vessel from a state of rest, or from a lesser degree of motion, the effort of the wind on the sails is greater than that of the water on the hull, whether to propel the vessel in the direction HE of the keel, or laterally, in the direction GH, and the velocity of the vessel in each of these directions, is accelerated by the excess of the force of the wind over the resistance of the water, until, ultimately, by the diminution in the relative velocity of the wind, and the increase of the relative velocity of the water, an equilibrium ensues between the propelling and the resisting forces, and the vessel continues to move in the direction of the last acting force, and with the last acquired velocity. Now the resistances of the water in the direction EH and HG increase as the squares of the velocities, and from the nature of the form of a vessel, and from the comparative direct and lateral resisting areas, the resistance arising from form or area, is much smaller in a direct than in a lateral direction, and therefore the equilibrium between the forces which act laterally, may ensue before that between the forces which act directly; in which case the lateral motion of the vessel will become uniform before the direct motion, and consequently the ultimate course of the vessel, when all the forces have arrived at a state of equilibrium, will approximate with that of the last acting force, that is, will more nearly coincide with the direction of the keel; and the angle of lee-way will be diminished. As this reasoning depends on the intensity of the force of the wind, the effect will vary as the cause; and the greater the force of the wind, and consequently the velocity of the ship, the greater must be the diminution of the angle of lee-way; that is, the angle of lee-way will vary inversely as the sine of the angle of incidence of the wind on the sail.

Romme, in his *Traité du Navire*, differs from the opinions advanced by Bouguer, and though his reasoning on this subject

is far from clear, his opinions are valuable, as he founds the conclusions at which he arrives, that the lee-way varies inversely as the square of the velocity, and that it increases with the obliquity of the sails to the keel, principally on observations and experiments on the actual performances of vessels, and these are the only means by which, as yet, we can hope to arrive at the solution of this problem. However, much further observation is necessary to afford sufficient data on which to found an approximation to the lee-way which a vessel makes: the general facts which influence it appear to be,—the greater or lesser angle of incidence of the wind on the sail, as the velocity of the ship is dependent on this;—the angle of the inclination of the sails with the keel;—the force of the vessel as it affects the ratio of the direct and lateral resistances;—the form of the vessel as it affects the velocity;—the stability, as it affects the lateral resistance;—the quantity of sail set, and the state of the sea.

The distance which a ship falls to lee-ward of her course in any given time, may generally be very easily ascertained, and it would not be a task of any great difficulty to form tables, from actual observation, for ships, under all the various circumstances which have been shown to affect the deviation of their course, from the line of direction of the keel. In the open sea, the quantity of lee-way made in any certain time may be easily ascertained, by measuring the angle which the ship's wake makes with the line of the keel, then if the distance run during the time for which the lee-way is to be observed be ascertained, as that distance is measured along the line of lee-way, the distance run in any period of time, will be to the distance which the ship has fallen to lee-ward of her course during that time, as radius to the sine of the angle of lee-way. When a ship is in sight of land, the angle which the direction of the keel makes with the line of lee-way, may be more correctly observed by means of a fixed object on the shore, whenever the state of the wind and sea may render an estimation of the lee-way desirable, that is, whenever the wind is sufficiently steady, as, of course, it is supposed that the angle formed by the direction of the wind with the line of the keel, will remain constant during the whole time for which the dis-

tance fallen to lee-ward is to be ascertained. If, when the ship is either approaching or leaving the shore, her head be constantly kept to the same point of the compass, the ship's course will be along the line of lee-way, and, as all things are supposed to remain constant during the time of the observation, this line will form a constant angle with the line of the keel, and therefore the point in the shore, which will be in the same bearing from the ship as the line of lee-way, will remain in that bearing during the whole time in which the ship either approaches to or recedes from the shore, consequently, if when a ship either approaches to or recedes from a shore, a point be observed which has a constant bearing from the ship, it must be in the direction of the line of the lee-way; and therefore the angle which it makes with the direction of the keel will be the correct angle of lee-way; and then as before, if the distance run in any time be taken as the radius, the distance which the ship has fallen to lee-ward of her course in that time, will be equal to the sine of the angle of lee-way to a radius equal to the distance run by the vessel in the time assumed.

The actual quantity gained to windward in any given time may also be easily ascertained. The motion of the vessel through the water may be considered in four directions, and the velocity with which it advances in either of these directions ascertained. The actual velocity of the ship, or the velocity along the line of lee-way, which may be called the oblique velocity, may be resolved into two, the direct velocity, or that estimated in the direction of the keel, and the lateral velocity, or that which is in a direction at right angles to the line of the keel; and cotemporaneous with these is the velocity with which the ship gains to windward. Let AB, fig. 50, be the direction of the line of the keel of the vessel, and EF the direction of the yard, cutting the direction of the keel obliquely. Then whatever may be the direction of the wind GH, the course of the vessel will be along some line HK, forming an angle KHB with the direction of the keel; then suppose HK on the line of leeway to represent the velocity of the ship in that direction, from K draw KL perpendicular to HB, and cutting HB in L; then the velocity HK is equal to the two velocities HL and LK; and HL and LK will represent respectively the

direct and lateral velocities of the vessel, in proportion to the oblique velocity HK; and if from the points H and K, HM be drawn perpendicular, and KM parallel to the direction of the wind GH, MK will represent the velocity with which the ship has gained to windward, in the time in which she has described the space HK. For the origin of the wind being supposed to be at an infinite distance from the vessel, as HM is drawn perpendicular to GH, the direction of the wind, it may be supposed parallel to the origin of the wind; and as the angle GHK is less than the angle GHM, the line HK is within the line HM; and therefore the point K is nearer the origin of the wind than the point H, by a quantity equal to the perpendicular distance KM, of the point K, from the line HM; or the ship has gained the distance MK to windward, in running from H to K. It is evident that if HM coincided with HK, the ship would neither have gained to windward or fallen to lee-ward; and that if HM fell within HK, the ship would have fallen to lee-ward. When the distance HK run by the vessel along the line of lee-way, and the angle of lee-way KHL, are known, the value of KM may be easily determined, for since the angles GHF, FHL, and LHK, are all known, and the line MH is drawn perpendicular to HG, their complement, the angle MHK, is known; therefore as HMK is a right angle, HK is to KM as radius is to the sine of the angle KHM; or, KM is the sine of the angle KHM, to a radius equal to the distance run by the vessel in the space of time in which the required distance to windward, KM, was to be gained. The only difficulties in the practical solution of this proposition are, to determine the direction HM, or the perpendicular to HG the direction of the wind, and the value of the angle GHF: for when the vessel is in motion, unless the directions of the wind and of the course of the vessel coincide, that is, unless the vessel is before the wind; the direction of the wind as shown by the vane on board will not be its true direction; for, from the velocity of the passage of the vessel through the air, the vane is subjected to a force acting upon it in a direction opposed to that of the course of the vessel, the effect of which may be considered the same as if the vane was at rest, and was acted upon by a current of air having a velocity equal to that of the vessel, but acting in an

opposite direction; consequently, the vane is acted upon by two forces, the one in the real direction of the wind, acting with a velocity equal to the velocity of the wind in that direction; and the other acting in a direction opposed to that of the course of the vessel, with a velocity equal to that of the vessel in its course; and consequently the direction of the vane will be the diagonal of the parallelogram of these two forces; it is therefore evident that, all things else remaining the same, the greater the velocity of the vessel, the more will the direction of the wind as shown by the vane, or the apparent wind, deviate from the actual direction of the wind, or the true wind; and as this deviation arises from the action of a force in a direction opposed to the motion of the vessel, or acting from the fore part of the vessel towards the after part, the apparent direction of the wind will, in all cases, head the vessel more than the true wind, and consequently the vessel will always appear to lie nearer the wind than she actually does.

The true direction of the wind may be found if the velocity and direction of the vessel be known, and also the velocity and direction of the apparent wind, as the corresponding velocity and direction of the true wind, will form the third side of a triangle, of which the three sides will be to each other as the three velocities; and as two of these are known, and include a known angle, that formed by the direction of the apparent wind with the course of the vessel, the third side, or the direction and velocity of the true wind, may be easily found. But as there is a difficulty in ascertaining the velocity of the apparent wind, the most easy way of determining the direction of the true wind, will be by observing the arc through which the ship's head passes from close hauled on one tack, to close hauled on the opposite tack; the bisection of this arc will, all things else remaining the same, give the direction of the true wind, as the course of the vessel in relation to the direction of the wind will be the same on either tack. Or, the directions of the apparent wind may be observed both before and after tacking, and the true wind will be the middle point between the two directions, as the cause of the deviation of the direction of the vane from that of the true wind, or the velocity of the vessel, will be equal on each tack; and when the direction of the true

wind is known, all the other parts of the triangle may be found, as the direction and velocity of the ship are known, and also the angle made by the apparent wind with that direction.

Should the velocity of the vessel be greater on one tack than on the other, it will be necessary, in order to determine the direction of the true wind, to divide the angle described by the vane when the ship is tacked, into two segments, which shall be to each other in the inverse ratio of the velocities of the vessel on the tacks adjacent to the segments.

Writers on Naval Architecture and on Seamanship, appear to have fixed the limit of the angle which is formed by the direction of the wind with the line of the keel when a ship is close-hauled, at 6 degrees. This exceeds the angle which the writer of this article has repeatedly observed by the means which have been described, as being formed by the direction of the wind with the line of the keel, on board the Acorn, one of the corvettes of the experimental squadron of the year 1827. The following table will show the results of some of the observations then made.

Ship's head before Tacking.	Ship's head after Tacking.	Number of Points difference.	State of the Wind.
SSE. ½ E.	W. ½ N.	10	Fresh breeze.
W. by S. ½ S.	SSE. ½ E.	9	Light airs.
SSE. ½ E.	W. by S. ½ S.	9	Light airs.
W. ½ N.	N. by E. ¾ E.	9¼	Moderate.
N.W. by N.	E. by N.	10	Fresh breeze.
SSE.	W.	10	Very fresh.
W. ½ S.	SE. by S.	10½	Very fresh.

The second and third observations in this table were made on the same day; their correctness receives further confirmation from the circumstance that when the Acorn was on the larboard tack, with her head W. by S. ½ S., the Columbine, another corvette of the squadron, was on the Acorn's beam, lying about SE. by S. on the starboard tack; she must therefore have been lying as near the wind as the Acorn. The wind was very light, the rate by log being only 1 knot 2 fathoms, the

angle of lee-way as observed by the wake was 7 degrees. It is desirable that similar observations should be made for all classes of ships; the circumstances of sea, wind, &c., should also be noticed, that when any comparison is instituted, a due allowance may be made for their influence.

We have seen that the velocity of the ship depends on the strength of the wind; writers on naval architecture have advanced various opinions as to the practicable limit to the velocity of a ship, in comparison with that of the wind; Bouguer endeavours to prove that the velocity of a fast-sailing ship is, when going nearly before the wind, about $\frac{4}{7}$ of the velocity of the wind; and that merchant ships seldom attain to more than $\frac{1}{3}$ of its velocity, but he considers it not impossible that fast-sailing frigates may arrive at a velocity about equal to $\frac{1}{2}$ that of the wind. Don Juan objects to Bouguer's limit as too restricted; he corroborates the opinions he advances by the results which he has deduced from experiment and observation on the actual performances of ships; he says, that fast-sailing vessels acquire a velocity nearly equal to that of the wind, even when going before the wind. The nearest approximation to this velocity which he observed was as 21 to 23; the average conclusion at which he arrives, is, that when the course of the ship and the direction of the wind nearly coincide, the velocity of the ship is from $\frac{2}{3}$ to $\frac{20}{27}$ of that of the wind.

But in oblique courses, it is very possible for the vessel to acquire a velocity even greater than that of the wind; if we admit the conclusions of Don Juan to be correct, the reason of this will appear evident on very slight consideration. The velocity with which the wind acts on the sails after the ship has acquired motion is only its relative velocity, that is, the excess of its actual velocity above the velocity which the ship has acquired in the direction of the wind; now, when the directions of the wind and of the course of the vessel coincide, this relative velocity of the wind is only the difference between the actual velocities of the wind and of the vessel, but when the course of the vessel is oblique to that of the wind, the relative velocity of the wind is the difference between the actual velocity of the wind and that part of the velocity of the vessel which can be resolved in the direction of the wind. Robison, in his Treatise

on Seamanship, says, that when the sails are square to the keel, and the wind right aft, the ship's velocity is in direct proportion to the relative velocity, and to the square root of the surface of the sails: therefore, he says, "in order to increase the relative velocity by an increase of sail only, we must make this increase of sail in the duplicate proportion of the increase of velocity."

When the sails are oblique to the keel, he says, "the velocity of the ship is proportional to $\sqrt{S.V.}$ *sin.* a; that is, directly as the velocity of the wind, directly as the sine of the absolute inclination of the wind to the yard, and directly as the square root of the surface of the sails:" this agrees with the conclusions that have been already drawn; and it is evident, that the velocity of the wind remaining the same, and the sine of the angle of inclination of the wind to the yard becoming equal to the radius, or, if the whole force of the wind act in a direction perpendicular to the yard, the velocity of the ship will depend on the area of the sails set, and may therefore even, theoretically speaking, be increased without limit.

From all the conclusions which have been deduced in the course of these remarks, on the mutual action of the wind and water on a ship, it appears evident that the degree of perfection in the performance of a ship, whether with reference to her motion round an axis of rotation, or to her course through the water, depends very greatly on the suitableness of the disposition and proportions of the sail in reference to the form of the vessel; that there should be an analogy between these elements is evident, and experience and reason alike show that the more nearly the rig of a ship is suited to the qualities of her form, the more nearly do her performances approach to perfection. Vessels which from the proportions and form of their bodies are capable of lying near the wind, and maintaining a weatherly course, cannot evidently avail themselves of these advantages unless their rig is adapted to such qualities; while vessels of which the form and proportions are not so perfect, with reference to performance in oblique courses, by having a rig peculiarly adapted to such, may even be unable to acquire their maximum of advantage in direct courses. The limits to which these considerations may be carried, and the

connexion between the form and proportions of ships, and the various species of rig, will form the subject of a future article.

Art. XIII.—*Account of the Establishment of Officers in the Royal Dock Yards of France.* (*From the Annales Maritimes.*)

Ordinance of the King, establishing the Organisation of the Royal Corps of Naval Engineers.

Paris, the 28th March, 1830.

Charles, by the Grace of God, King of France and of Navarre;

On the report of our Minister Secretary of State for the Marine and Colonies,

WE HAVE ORDAINED, AND ORDAIN, AS FOLLOWS :—

CLAUSE I.

Of the Formation of the Royal Corps of Naval Engineers. (*Génie Maritime.*)

Art. 1. The engineers charged with the direction of the building of our vessels, and of the works connected with this service, shall compose the corps of naval engineers.

This corps shall bear the title of "Royal," and the officers belonging to it shall enjoy all the prerogatives and advantages attached to this title.

2. The Royal Corps of Naval Engineers shall consist of the following :—

1 Inspector General,
5 Directors of Naval Constructions,
10 Engineers of the 1st class,
12 Engineers of the 2nd class,
12 Sub-Engineers of the 1st class,
12 Sub-Engineers of the 2nd class,
5 Sub-Engineers of the 3rd class.
—
57

And of a number of cadets, to be regulated according to the demands of the service.

CLAUSE II.

Of the Admission and Instruction of the Cadets of the Naval Engineers.

3. The cadets of the naval engineers shall be taken from among those students of the Polytechnic School who shall have been declared worthy of admission into the public services, and according to the regulations established in that school for the final examination of the students.

They shall pursue for two years, at the port of Lorient, under the direction of an engineer of the 1st or the 2nd class, to be nominated by our Minister of Marine, a complete course of the application of theory to naval architecture.

They shall also be exercised in making drawings of ships of war, and in the details of their masting, sails, fittings, and equipment.

In the calculations of displacement, of stability, of the centres of gravity, and of sail, and all others relative to the theory of naval architecture.

In the study of steam and other engines, which may be of useful application, whether in the arsenals, or on board ships of war.

In designing ornamental work, and in drawing in water-colours.

In the study of the English language.

They shall be frequently taken to the docks and workshops of the arsenal, that they may acquire a knowledge of the various processes followed in the building of ships of war, and in the preparing of the various objects necessary for their equipment.

They may also, having the permission of the Prefect of Marine, and being accompanied by the engineer charged with the direction of their studies, visit the principal manufacturing establishments which may exist in the neighbourhood of Lorient, in order that they may acquire a knowledge of the various processes which are carried on in them.

More detailed directions, for regulating the studies and em-

ployment of the cadets, will be eventually approved by our Minister for the Marine and Colonies.

4. At the expiration of a course of two years' study, the cadets will be subjected to an examination in the various branches of instruction which they shall have received. Those who shall pass through the examination in a creditable manner, and shall be declared by the examiners to be qualified, will immediately receive the appointment of sub-engineers of the 3rd class; their seniority in this rank will be determined according to the results of the examination.

Those cadets who shall not have been considered as sufficiently qualified, will be permitted to continue their studies for a third year; at the expiration of which period they will be finally rejected, unless they have become possessed of the qualifications which are required.

The Prefect of Marine shall preside over the commission appointed for the examinations, which shall be composed of the Director of Naval Constructions, the Director of Hydraulic constructions, of an officer of the naval engineers, and of a professor of mathematics.

The examination shall be public.

5. The engineer charged with the instruction of the cadets, shall himself write the course of the theory of naval architecture, and of mechanics applied to the arts, which they are to read.

He may also participate in the direction of the works carrying on in naval construction.

He shall forward a report every three months to the Prefect of Marine, on the conduct and on the progress of the cadets; and he shall also propose to him such measures as he may consider would contribute to perfecting the studies, with the direction of which he is entrusted.

CLAUSE III.

Of the Promotion and Duties.

6. The sub-engineers of the 3rd class shall be promoted to

the rank of sub-engineers of the 2nd class, by seniority, and according as vacancies may occur in this latter rank.

The sub-engineers of the 2nd class shall be promoted to the rank of sub-engineers of the 1st class, in the proportion of one-fourth from selection, and three-fourths from seniority.

The engineers of the 2nd class shall be made from the sub-engineers of the 1st class, in the proportion of one-third from selection, and two-thirds from seniority.

The engineers of the 1st class shall in the same manner be made from the engineers of the 2nd class, in the proportion of one-third from selection, and two-thirds from seniority.

The directors of naval construction shall be nominated by selection, from among the engineers of the 1st class.

The Inspector General of naval engineers shall be chosen from among the directors of naval construction.

7. The officers of naval engineers cannot be promoted to a higher rank, or to a superior class, without having previously served for at least three years in the rank or class immediately inferior.

8. The sub-engineers of the 2nd class cannot be promoted to the 1st class until they shall have made a voyage of at least one year

The sub-engineers of the 1st class must also pass a similar period at sea, previous to being promoted to the rank of engineers of the second class.

Notwithstanding this, the first year of service at sea may be performed by sub-engineers of the third class, who shall have already completed three years' service in this rank in any of the arsenals of the kingdom.

They may then complete the second year of sea service, which is required according to the above regulation, when they become sub-engineers either in the second or first class.

The officers of naval engineers are restricted by the present article to performing the sea service herein mentioned, either on board a line-of-battle ship or a frigate.

9. The sub-engineers embarked on ship-board, in fulfilment of the condition of the above article, will particularly direct their observations:—

On the details of the stowage, and the general equipment.

On the arrangement and the effect of the mechanical means employed in moving the top-masts, top-gallant-mast, and yards, and also in furling and unfurling the sails.

On the method of working the anchors.

On the effects which the shock of the waves, and the motions of pitching and rolling, have on the combination of the various parts of the structure, and generally, on every subject relative to naval construction.

Whenever they may have opportunities of visiting the ships of war, or the arsenals of foreign nations, they shall carefully examine them, and obtain the best information in their power on every thing which may appear to them worthy of imitation, either in our arsenals or on board our ships.

They shall keep watch on deck with the most experienced officer on board, having charge of a watch. They shall attend, under the orders of the second captain, to all the works which may be executed on board, whether to the ship or to the masting.

At the expiration of their voyage they shall make a detailed report of the results of their observations.

10. Excepting in cases where the exigencies of the service in the arsenals will not admit of it, an engineer of the 1st or 2nd class shall be embarked in each squadron and in each division under the command of an admiral (*officier general*).

This engineer shall fulfil the duties detailed in Clause XII. of the ordinance of the 31st October, 1827, on the naval service.

11. In each of the five principal naval arsenals, the senior engineer of the first class attached to the arsenal shall fill the situation of sub-director. He shall act for the Director of Naval Construction in all cases of absence, and shall be especially responsible for comptrolling the accounts.

He shall, notwithstanding, continue to fulfil the duties attached to his rank as engineer.

12. The Directors of Naval Construction shall fulfil the duties appointed to them by the ordinance of the 17th of December, 1828, on the service of the arsenals.

13. The Inspector General of Naval Engineers shall reside at Paris.

He shall correspond with the Directors of Naval Construction employed in the five principal arsenals, and with the officers

of naval engineers who are charged with similar duties in the secondary arsenals.

He shall be consulted on the stationing of the officers of naval engineers of all ranks, on their embarkation on board vessels, on their promotion in the cases which are guided by selection, and on their being permitted to retire on pensions.

He shall give his opinion on all plans for ships of war of all classes, and of the different accessory machinery; and also on all professional questions, and on the prices and schemes of work which shall be laid before him.

He shall, on receiving directions from the Minister of Marine, inspect the arsenals, to assure himself of the state of perfection of the various works.

He shall establish and maintain strict uniformity in the method of executing works of a similar nature in all the arsenals, and shall endeavour to introduce into all the departments of naval construction, the knowledge and the practice of all new processes tending to the improvement of the mechanical arts, and to economy of materials or of workmanship.

In fact he shall promote, by every means in his power, the improvement of naval architecture.

At the end of every year he shall submit to the Minister of Marine a report on all the branches of the service which are under his direction.

CLAUSE IV.

On the Appointments and other Allowances.

14. The appointments of the officers of the Royal Corps of Naval Engineers shall be regulated as follows :—

	Francs.
Inspector General (including the expense of lodging and table money) - - - - - - -	15,000
Directors of Naval Construction, at Brest, Toulon, and Rochfort - - - - - - -	8,000
Ditto, at Cherbourg and Lorient - - - -	7,000
Engineers of the 1st class - - - - -	5,000

	Francs.
Engineers of the 2nd class - - - - - -	4,000
Sub-engineers of the 1st class - - - - -	3,000
Sub-engineers of the 2nd class - - - - -	2,400
Sub-engineers of the 3rd class - - - - -	2,000
Cadets - - - - - - - - -	1,200

Supplementary allowances shall be made to the officers herein-after mentioned, in the following manner:

To the engineer charged with the instruction of the cadets - - - - - - - 1,000 fr.

To each of the engineers of the 1st class, in the five principal arsenals, who fills the office of sub-director - - - - - - - 400 fr.

15. The officers of the Naval Engineers when employed at sea, shall receive during the period of that service, a supplementary allowance equal to one fourth of their fixed appointments.

16. The Directors of Naval Construction in the five principal arsenals, and the engineers charged with the same duties in the secondary arsenals, shall continue to be allowed the office expenses which are fixed by the regulations.

The engineers and sub-engineers employed in the several arsenals, shall have an allowance of 200 fr. per annum for office expenses.

This allowance shall only be made to officers actually employed at the arsenals.

CLAUSE V.

Of the Comparative Rank, and Uniform.

17. The rank of the officers of Naval Engineers, in comparison with that of the Royal Navy and of the corps of Naval Administration, is fixed as follows:

Officers of the Naval Engineers.	Officers of the Navy.	Officers of Naval Administration.
Inspector General	Rear-Admiral	
Director of Naval Constructions.........	After the Rear-Admirals, and before the Post Captains (*Capitaine de Vaisseau*)	Commissary General
Engineer 1st class	Post Captain	Commissary of the Navy
Engineer 2nd class ..	Commander (*Capt. de Frigate*)	
Sub-Engineers, 1st class	Lieutenant......	Sub-Commissary 1st class
Do. do. 2nd class		Do. do. 2nd class
Do. do. 3rd class	Mate (*enseigne de Vaisseau*)	Principal Clerks
Cadet	Midshipman	

18. The uniform of the officers of the naval engineers shall be as follows:

The dress uniform shall consist of a cloth coat of royal blue (*bleü de roi*). Waistcoat and breeches of white cloth: it shall be worn with a white stock, shoes with buckles, and dress hat.

The coat shall be turned back with scarlet cloth; and buttoned close on the breast, with nine large uniform buttons; the collar and cuffs shall be of black velvet; the collar to stand up, and the cuffs to be cut round, open at the under part, to button with three small uniform buttons.

The pockets shall be in the folds of the skirt.

The turning back shall be united at each side by an anchor with a crown, in which is a *fleur de lis*.

The waistcoat shall be without embroidery; it shall button straight on the breast, with seven small uniform buttons; the breeches shall be worn moderately tight.

The uniform buttons shall be of gilt metal; the larger size shall have the device of an anchor with a cable, and surrounded by the motto "*Corps Royal du Genie Maritime.*" The smaller buttons shall have the anchor without the motto.

The hat shall be plain, without tassels. The loop shall be of gold fastened by a button similar to those on the coat. The hat of the Inspector General, and also those of the Directors

of Naval Constructions, shall be ornamented with a frizzed black feather, which shall be fastened to the inner part of the turning back of the hat.

The shoe-buckles and those of the knee-bands, shall be of gold, or of silver gilt, and similar in pattern to those used by the corps of Naval Administration.

The sword shall be of the pattern at present in use for the officers of the Royal Navy: the sword-knot shall be of gold bullion for superior officers, to the rank of engineer of the 2nd class inclusive; and of gold fringe for the officers of inferior rank.

The belt shall be narrow, and plain for all ranks.

Undress Uniform.

The undress uniform shall consist of a coat of royal blue cloth, short in the skirts; waistcoat and pantaloons of blue cloth, and black boots.

The coat shall have a stand-up collar and round cuffs, open at the under part, the whole of black velvet; it shall be without facings, and shall button on the breast; the pockets shall be in the folds of the skirts.

Marks distinguishing the Rank.

The rank of the officers of Naval Engineers shall be distinguished as will be explained, by embroidery of gold of certain fixed patterns. The embroidery for each rank shall conform in size and quantity to that for the corresponding rank in the corps of Naval Administration.

Inspector General.

Full dress. A double row of embroidery on the collar and cuffs; and a single row round the coat and on the turnings back, embroidered at the waist.

Undress. To be similar to the dress coat, with the exception of the embroidery on the front and on the skirts.

Director of Naval Construction.

Full dress. Embroidery and ornamented edging on the collar and cuffs; embroidery only round the coat, embroidered at the waist.

Undress. To be similar to the dress coat, excepting the embroidery round the coat.

Engineer of the 1st Class.

Full dress. Embroidery on the collar and on the cuffs; and edging on the front and on the turnings back, embroidered at the waist.

Undress. To be similar to the dress coat, excepting the edging on the front and turnings back; and no embroidery at the waist.

Engineer of the 2nd Class.

Full dress. Embroidery on the collar and cuffs, and embroidery at the waist.

Undress. Similar to the dress coat, and no embroidery at the waist.

Sub-Engineer of the 1st Class.

Full dress. Embroidery on the collar and cuffs only.

Undress. Embroidery on the collar only, the cuffs plain.

Sub-Engineer of the 2nd Class.

Full dress. Embroidery on the collar, and a plain edging on the cuffs.

Undress. Embroidery on the collar only.

Sub-Engineer of the 3rd Class.

A narrow embroidery on the collar only.

Cadet.

A plain edging round the collar and cuffs.

CLAUSE VI.

Temporary Regulations.

19. Those officers of Naval Engineers who held ranks which

have been either suppressed, or of which the denominations are changed by the present ordinance, shall be classed as follows:

The assistant inspector shall retain the title under which he has hitherto fulfilled the duties of his office.

The sub-directors of Naval Construction shall take the title of engineers of the first class, and shall be placed at the head of the list of the officers of that rank.

The engineers of the third class shall take the title of gineers of the second class, and shall be placed below the officers who at present hold that rank.

The cadets already admitted shall bear the rank of sub-engineers of the third class.

In this first formation, the classing of the officers on the list of the corps, shall be regulated according to the rank which each officer at present holds on that list.

20. Promotion shall only take place in the corps of Naval Engineers in the proportion of one half the vacancies, until the corps shall be reduced to the effective establishment fixed by the 2nd Article of the present ordinance.

21. The sea service mentioned in Article 8, shall not be required of those sub-engineers of the first class who at present form a part of the corps of Naval Engineers.

22. Our Minister for the Marine and colonies, shall determine each year on the number of officers of the Naval Engineers to be employed in the purveying timber for building.

The officers employed on this service in the interior of the kingdom, shall continue to enjoy the same supplementary allowances, travelling expenses, and leave of absence, as hitherto.

CLAUSE VII.

Of the Assistants to the Naval Engineers.

23. Persons under the denomination of assistants to the Naval Engineers (*adjoints du genie maritime*), shall be employed in carrying on the works and operations subordinate to the service of the arsenals: they may act for the engineers and sub-engineers in the receipt of materials or stores.

24. These assistants shall be twelve in number, and formed into three classes.

They shall be attached to the arsenals in the following proportion:

Brest	3
Toulon	3
Rochefort	2
Lorient	2
Cherbourg	2
	12

25. The appointments of the assistants shall be regulated as follows:

	fr. per ann.
1st class	2,400
2nd class	2,000
3rd class	1,600

26. Dating from the year 1831, until the total number fixed by Art. 24 shall be completed, three assistants of the third class shall be nominated yearly.

These assistants shall be nominated by examination, and our Minister Secretary of State for the Marine, shall decide on the ports at which these examinations shall take place.

27. The candidates for the situation of assistants of the third class, must be at least twenty-five and under thirty years of age; must have been employed during five years as petty officers in the arsenals or on board ships of war; must produce certificates of good conduct from the officers under whose orders they have served; must be able to write legibly and correctly; must know arithmetic and the elements of geometry, including the solids; must be able to copy plans of ships, and trace and draw machinery, and be acquainted with the quality of the various materials employed in naval constructions.

28. The candidates shall be examined by a commission consisting of:

A Major General of Marine, as president; two officers of the Naval Engineers, and of the Professor of Hydrography.

The Inspector or a Sub-inspector of Marine shall assist at this examination, of which notes shall be taken.

29. These assistants cannot be promoted to a higher class till

after having served a period of four years at least in the class immediately below.

The promotion of the assistants of the third class shall be proposed to the Minister of Marine, by the council of administration of the principal maritime stations.

The assistants of the second class who merit promotion to the first class, shall be nominated by the Inspector General.

30. These assistants shall be subordinate to the officers of Naval Engineers, and they shall assimilate for rank and retiring pension, as follows:

Those in the first and second classes, with the principal clerks of the marine, and those in the third class with the inferior clerks.

31. The uniform of the assistants of Naval Engineers, shall resemble the undress uniform of the Engineers, but the collar only of the coat shall be of black velvet, and ornamented with a *fleur de lis* in gold. The buttons shall be gilt metal bearing the device of an anchor, with the motto *Constructions Navales;* the small buttons shall bear the anchor without the motto. They shall wear a sword according to the regulated pattern.

32. Our Minister Secretary of State for the Marine and Colonies, is charged with the execution of the present ordinance.

We order and command the Admiral of France, the Prefects of Marine, the General and Superior officers of our Royal Corps of Marine, and all others whom it may concern, to aid and assist in the execution of this present ordinance.

Given at Paris, in our Palace of the Tuileries, this 28th day of the month of March, in the year of grace 1830, and of our reign the sixth.

By the King. *Signed* Charles.

The Minister Secretary of State for the Marine and Colonies.

Signed Baron D'Haussez.

Louis-Antoine, son of France, Dauphin, Admiral of France;

We have seen the above ordinance which is addressed to us;

We order and command the Prefects of Marine, the civil and military officers of Marine, and all others whom it may concern, to aid and assist in the execution of this present ordinance.

Given at Paris, the 4th April, 1830.

Signed Louis-Antoine.

By the Dauphin. *Signed* The Chevalier de Panat.

Art. XIV.—*Notice of "an Explanation of a correct method of Admeasuring Ships, for ascertaining their Tonnage, with three Examples of its application to Vessels in the Coal Trade;" by William Parsons, late of the School of Naval Architecture, Portsmouth.*

This excellent little pamphlet explains very clearly the correct method of determining a ship's tonnage. By the tonnage is understood, the quantity of lading, in tons, a ship is capable of carrying; which can be accurately determined by calculating the difference between the displacement, when completely laden, and the displacement when every thing is on board except the lading. See Articles XIII. XXIII. and XXIX. in Vol. I. of this work.

Our object in noticing this little work is, not to consider its applicability to the measurement of colliers, the propriety of which the author insists on with considerable ability, but to show the correctness of its principle, and the propriety of its general use.

The want of a correct method of measuring the lading of merchant ships is continually experienced in levying dues in proportion to their tonnage; its use in comparing the magnitude of ships of war is of much less importance. The incorrect method at present in use is injurious in two respects: the fraud constantly practised in building merchant-ships to carry much more than their nominal tonnage; and the effect which this object, in their construction, has in preventing their being built of such dimensions and form as to possess the essential quali-

ties of good ships. The elements of the present rule are the length and breadth of a ship, the depth and form not entering into it, half the breadth being substituted for the depth in the calculation. "This method of measuring the tonnage is evidently erroneous; for if two vessels are of the same length, have the same rake in their stems and sternposts, but the breadth of one is double the breadth of the other, then the broadest will measure four times as much as the narrow one; whereas it ought to measure only twice as much. The draught of water being omitted in the rule, the practice of increasing the depth has become general, by which means the vessels are capable of carrying a greater burden without increasing the register tonnage." The author also shows the error of neglecting the form in the present rule for tonnage.

Mr. Parsons gives an ingenious explanation of its probable origin. "The origin of this rule, in the absence of authentic information on the subject, may be traced in the following manner. It is well known that any body floating in a fluid displaces a volume of that fluid, the weight of which volume is equal to the whole weight of the floating body. Thus, a ship floating in water displaces a volume of water which is equal in weight to the whole weight of the ship, and every thing on board. This displacement of a ship, or the whole weight of the stores, cargo, and every thing on board, together with the weight of the hull, must always bear some relation to the principal dimensions of the ship, namely, to the length, breadth, and draught of water, or to L, B, and D. Now it is known, from calculations on vessels with rather full forms for burden, that the displacement, estimated in cubic feet of sea-water, is equal to sixty-two hundredths of the product of these three dimensions, or equal to $L \times B \times D \times ,62$; which being divided by 35, the number of cubic feet of salt water which weigh a ton, will give the displacement in tons $= \frac{L \times B \times D \times ,62.}{35.}$ The draught of water of men-of-war is generally about half the extreme breadth of the ship, and no doubt that at the time of the formation of the rule for tonnage, it was in the same proportion in merchant vessels; but being omitted in the rule

for tonnage, this dimension has very much increased of late years, without a relative increase in the length and breadth; therefore, instead of D, substitute what was formerly its equivalent, $\frac{B}{2}$, and the expression becomes

$$\frac{L \times B \times \frac{B}{2} \times ,62}{35}, \text{ or } \frac{L \times \frac{B^2}{2} \times ,62}{35} = \text{the whole displace-}$$

ment, or weight of the vessel in tons. The weight of the hull, stores, &c. was generally about two-fifths of the whole weight, leaving three-fifths for the weight of the cargo, or burden.

Therefore, $\frac{L \times \frac{B^2}{2} \times ,62}{35} \times \frac{3}{5} = \frac{L \times \frac{B^2}{2}}{94}$ = burden in tons, which is the common rule."

The inaccuracy of the present rule is generally admitted; the object now is to substitute for it a correct method. We most perfectly agree with those who refuse their assent to the adoption of any method, however simple in its application, which is not on correct principles. We do not wish to see the error diminished, but abolished. Simplicity is desirable, and to a certain extent necessary, but it should not be obtained by a sacrifice of principle. The scale of tonnage has been frequently recommended, and the trouble of constructing it for every class of ships has, we conceive, been the only cause of its being so long neglected to be carried into execution. Mr. Parsons has undertaken this work for all classes of ships of the royal navy, and for various kinds of merchant ships. The scales of tonnage of three vessels are given in the present work. The scale of tonnage is constructed by calculating the cubic contents in tons of horizontal portions of a ship's displacement at various heights above the lower edge of the keel, and by drawing ordinates perpendicular to a vertical line at the different heights, representing by scale the corresponding portions of the displacement; a curved line drawn through the extremities of these ordinates is the scale of tonnage.

Mr. Parsons has constructed his scales in two parts, one for

the fore body and the other for the after body, the body being divided at the middle of the length of the load-water line, between the perpendiculars at the fore part of the rabbet of the stem and the after part of the rabbet of the sternpost. Fig. 51 is the scale of tonnage of a brig of 170 tons, register tonnage, drawn on a smaller scale than that given in the work. "The tonnage, or actual weight, that this brig is capable of carrying, is found from these lines, in the following manner:—Suppose the vessel has every thing on board except the cargo, and the draught of water is six feet at the stem and sternpost, or on an even keel; set this distance up from the base line, or lower side of the false keel, and draw out the line A 12 parallel to the base, intersecting the line 1, the line of tonnage for the after body, in B, the distance AB, applied to the scale of tons, will measure 46 tons, the weight of the after body; the same line A 12 intersects the line 2, the line of tonnage for the fore body, in C, the distance AC will measure 64 tons, the weight of the fore body: therefore the whole weight of the vessel, with every thing on board, except the cargo, is 110 tons. Now suppose the cargo is put on board, and that the draught of water is 12 feet at the stem and sternpost, or 12 feet on an even keel; proceed as before to find the weight of the vessel at this new draught of water; the line D 11 is drawn at 12 feet from the base, and the corresponding weight of the after body is 157 tons, and of the fore body 193 tons, therefore the whole weight is 350; but the weight before the cargo was put on board was 110 tons, consequently, the weight of the cargo must be 240 tons." When there is a considerable difference in the draught of water at the stem and sternpost, Mr. Parsons observes, it may be necessary to take the medium depth for each body, instead of the depth at the middle of the vessel.

Mr. Parsons informs us, that "this pamphlet will in a short time be followed by a larger work on the same subject, containing lines of tonnage for vessels of every description, and a full explanation of the use of the other lines in the plates, which have not been noticed in this pamphlet." The line 3, represents the whole area of the horizontal sections, in square feet, of the after body; the line 4, of the fore body. The line 5, represents the whole exterior surface of one side of the vessel,

in square feet of the after body; the line 6, of the fore body. The line 7 represents the whole area of the vertical sections, as high as the load-water sections, in square feet, of the after body; the line 8, of the fore body. ⊕. ⊕, give the situation and form of the principal transverse section; 9. 9, give the situation and form of the section in the after body, whose area is equal to two thirds the area of the principal section; and 10. 10, in the fore body; 11 is the load-water line, and 12 the light-water line.

Such a work will be of the greatest practical utility to naval architects, by very greatly facilitating numerous operations which require tedious calculations; and may thus lead to many important investigations, which may conduce essentially to the interests of naval architecture.

Art. XV.—*Notice of "A Description of Commander Marshall's New Mode of Mounting and Working Ships' Guns, &c.*

The necessity which exists of perfecting the artillery practice on board our men-of-war, which has been so ably insisted upon in Sir Howard Douglass's introduction to his "Treatise on Naval Gunnery," appears to be most fully admitted by naval men; Captain Marshall's work, therefore, cannot but meet with the attention which the author claims for it from the members of his profession, as "an inquiry into a method by which the guns of the British fleet may be worked with greater rapidity—more extensive powers of operation—less labour—and more certain effect, than has ever before been practicable."

The difficulties which attend the acquirement of perfection in gunnery, are far greater at sea than on land. In land practice the gun and the object to be struck are generally stationary, while in most cases at sea, and particularly in distant firing, when accuracy of fire is of most importance, not only the relative positions and distances are constantly altering, but the gun is frequently in such rapid motion, from the effect of the waves on the vessel, that nothing short of instantaneous precision of aim can possibly be effective. In fact, the difficulties

attendant on perfecting the practice of naval gunnery are so great, that equal certainty of effect, with that which may exist on land, cannot be expected; at the same time much advantage may be derived from endeavours to diminish the influence of the obstacles which oppose themselves to it. The efficiency of a ship of war evidently depends, not only on the means of offence or defence which she may possess, but also on the facilities which are afforded by her equipment for perfecting the application of those means. If it is possible to lessen the interval between the discharges of a gun, or to increase the effect of the discharge, by assuring a greater degree of accuracy of aim, the force of the vessel may be said to be increased proportionately to its increase of efficiency. Both rapidity of fire and accuracy of aim must greatly depend on the ease with which the gun can be manœuvred; the latter can only be assured by a degree of ease of manœuvre which it appears almost impossible can be attained with so great a weight as that of the larger sea ordnance, under all the disadvantages which must necessarily exist. Various attempts have been made to lessen the effect of these disadvantages, by improvement of the carriage on which the gun is supported, but the exigencies of the naval service present many obstacles to perfecting this simple machine; so much so, that in spite of the objections against it, the present carriage for ship-artillery appears to have been in use almost from the first introduction of heavy artillery on board ships, and is generally adopted by nearly every maritime nation.

A carriage for ship-artillery should offer no obstruction to the guns being trained to the greatest angle either, before or abaft the beam, which the size of the port will admit; and the muzzle of the gun, when it is discharged, should be sufficiently out of the port to carry the fire clear of the ship. The carriage should also allow of the gun's being trained to the greatest necessary angle without requiring too large a port-hole: it should admit of the gun's being depressed or elevated as much as may be necessary under any circumstances of inclination at which it may be possible to fight the ship; it should be extremely difficult to be overturned, that it may resist any tendency to this which may arise from the guns being fired

under circumstances of great motion or inclination of the ship; it should possess facilities for enabling the guns to be loaded by the men when they are sheltered from the musketry of the enemy; it should be capable of being easily transported from one part of the ship to another; should not be easily put out of order, but when so, should be easily shifted; should occupy small space, and should be composed of the least possible quantity of materials, as both space and weight are necessarily economised on ship-board. The chief objections to the carriage at present in use, are the small facility it affords for motion in any other direction than lengthwise of the gun, and its confined angular range; in other respects it is not ill adapted to the service which is required of it.

The principal attempts at improvement in the gun-carriage have been directed to obtain separate facilities for the motions of the recoil and the training. The general principle adopted in most of these attempts has been similar to that on which the carriage for carronades, at present in use, is constructed; the having the carriage in two parts, the lower part, or base of the carriage, fitted to admit of its being easily trained in a fore-and-aft direction of the ship; and also to form a platform for the upper part, to which the gun is fixed, and which moves on the lower in the direction of the recoil. Chapman appears to have been the first who applied this principle to naval ordnance. In his carriage the gun was mounted, by its trunnions, on a shallow bed, similar in shape to the carriage for long guns at present in use, but without the trucks, the elevation or depression being regulated by quoins as at present; this bed was connected to a thick sole-piece, by means of a strong bolt which passed vertically through the breast ends of the bed and sole-piece, and formed an axis round which the bed might be turned on the sole-piece; these parts formed the upper division of the carriage; the lower division consisted of a slide on which this was to move, in the direction of the recoil, between two ribbands. The breast end of this slide was strongly connected with the ship's deck by means of a wooden pin, round which the slide might be traversed; to facilitate this motion the breech end of the slide was fitted with trucks, to run in a fore-and-aft direction of the ship. This carriage was used for some time in

the French navy, but has been long discontinued; for though it possessed great advantages in admitting of the gun's being easily worked and traversed, and in enabling the gun to be loaded with convenience in-board, without its being necessary to alter either the direction or elevation; it was of great extra weight, and occupied a very large space on the decks.

The carriage proposed by M. Paixhans, and described in Art. XXII. Vol. II. of this work, was on the same principle as this of Chapman's: the directing bar in that carriage offers the same facilities for traversing which the slide does in Chapman's; and the motion of the recoil is checked in both by the same means, the absence of the trucks. There have been several other modifications of the same principle, some of them are partially introduced in our service.

But the most remarkable innovation on the system of mounting ship artillery was the introduction of the principle of non-recoil, by General Sir Samuel Bentham. This gentleman, founding his conclusion on the fact, that neither mortars nor swivels, the largest and smallest ordnance which are used on ship-board, are fitted to admit of more recoil than that which results from the elasticity of the materials of the ship, and of the fluid on which he is supported, conceived that the same principle might be applied to all the intermediate species of ordnance, but especially to the shorter sorts, as in the longer it would, in many circumstances, be attended with great increase of difficulty in loading. This method of mounting ships' guns was partially introduced into our navy during the war, and more generally in the French navy, after 1810; but although it was found to possess great advantages over the old method, in requiring but few men to work the guns, and in admitting of the guns being fired much oftener in the same space of time, it was necessary to have large port-holes, and the men were much exposed while loading the gun. It appears that these disadvantages more than counterbalanced the advantages, as the system has been completely discontinued in this country, and, we believe, very generally so in France; though, from the statements which have been lately published by General Bentham, on the subject of these carriages, it is probable that there are many circumstances, especially in the arma-

ment of small craft, a species of force which must accompany the application of steam to warlike purposes, in which the principle of mounting large guns on non-recoil carriages may be advantageously introduced. The first recorded proposal for fitting guns on non-recoil carriages is due to Chapman, though his application of the system was limited to the smaller species of ordnance. The guns were mounted by their trunnions on the brackets of a small carriage, the bottom of which was formed by a thick piece of plank, having a circular mortice worked on its under surface, in depth about one third the thickness of the plank, and in breadth about two thirds the breadth of the plank; this carriage was placed on a stand formed to receive it; one end of which was secured to the port-sill, and the other end to a chock on the deck: a circular tenon was worked on the upper surface of the stand to correspond with the mortice worked on the under surface of the carriage, and a bolt in the centre of the tenon passed through both carriage and stand, forming the axis round which the gun might be traversed. This method of fitting admitted of no recoil.

The mounting of the gun, on Captain Marshall's principle, is composed of two distinct parts, which he has designated the breast and breech carriages. The breech carriage is connected to the gun by the trunnions. The breast carriage is independent of the gun; it is connected to the ship's side, and is merely intended as a rest, from the trunnions outwards, for which purpose it is fitted with an iron crutch to receive the gun.

Fig. 52 " represents a twenty-four pounder mounted upon the new carriage; at the breech it is supported upon the two-wheeled breech carriage, which, being attached to the trunnions, moves with the gun in every direction; at the fore part of the gun, upon the breast carriage; which being bolted to the ship's side remains stationary, whilst the gun runs in and out over the block in the crutch * * * * * The gun is prevented from running out any further by the trunnions, or trunnion rim, coming in contact with the crutch; and when the gun is run in, the approach of the muzzle any nearer to the crutch, or the danger of its recoiling too far through it, is not only prevented by a stout breeching, but doubly guarded against by a strong

breast rope, fixed to the breech carriage, and passed round the crutch, as shown by the figure. Thus are the two parts of the carriage prevented from approaching into contact, or of receding too far from each other, whilst the gun itself preserves the communication between the two parts of its carriage."

We have said that a principal objection to the old gun-carriage, is the small facility it affords for lateral motion, when it is required to be traversed, in order to fire either before or abaft the beam; Captain Marshall's carriage possesses a great advantage in this respect. The manner in which the breast carriage is connected to the side of the ship, is by means of strong eye-plates on the carriage, with corresponding eyes on the ship's side at the centre of the port. An iron bolt passes vertically through these four eyes, forming an axis round which the breast carriage may be traversed by means of small tackles, and as the pin of the crutch which supports the gun is fitted to turn in the carriage, the muzzle of the gun may by these means be moved from one side of the port to the other, "it is not necessary in training round to move the breech and the breast carriage at the same moment; nor are both these parts of the carriage required to be in the same line when the gun is fired. By moving either the breast or the breech of the gun, the aim may therefore be altered, and the breech carriage may recoil in any direction without producing any twisting strain upon the crutch or breast carriage * * * * * When a gun upon the new carriage has been trained to something like a required position, the aim is adjusted by moving the breast carriage instead of the breech, by which means a man at each breast tackle is enabled to draw the muzzle horizontally to one side or the other, with a motion so smooth and gentle, that the eye of the marksman is never thrown off the apertures of the sights till he perceives his aim to be true, when he is enabled instantly to fire; since the men whilst in the act of moving the gun are perfectly clear of the recoil. By this method of pointing much time is saved, and the eye and attention of the gunner not being required to be diverted from his object from the time he begins to take aim to the time he pulls the trigger, many causes of impatient and inaccurate firing are removed."

From the comparative ease with which the guns when mounted on Capt. Marshall's carriages can be worked, it follows

that the number of hands necessary to work them must be much fewer than is required by the present carriages, and consequently this involves all the advantages which may arise either from enabling ships to carry a greater comparative proportion of stores, or from lessening the necessity of sacrificing other qualities to stowage in the construction of new ships, for "that the guns employ more men to work them, than are wanted for all the purposes of navigation, &c., may be inferred from the reduction which is made in ships' crews when put upon the peace establishment, or when sent on service unconnected with naval armament;" besides, "in materially reducing the number of men required to perform a variety of laborious duties where so little room is afforded, order and convenience must evidently be promoted; and the loss of many lives be prevented, by distributing the men more thinly on the decks."

We shall quote the results of the experiments which were made on this carriage on board His Majesty's ship Prince Regent, at Chatham, as they place its qualities, in comparison with those of the old carriage, in a clear point of view.

No. 1. The respective guns, one a twelve-pounder mounted upon the established carriage, the other a twelve-pounder upon the new carriage, were trained to the greatest angle before and abaft the beam of their ports which their carriages would allow: their muzzles being each placed outside of their ports. Angle of the new gun 54°. Angle of the old gun 39°.

No. 2. The new gun, worked by three men, was trained from an angle of 54° on one side of the beam of its port, to 54° on the opposite side; and the old gun, worked by six men, was trained from an angle of 39°, to 39° in the opposite direction. Time in which the new gun was trained 25″, old gun 29″.

No. 3. The guns were each fired eight rounds, and pointed alternately at objects on the beam, three points before the beam, and three points abaft the beam. The time in which eight rounds were fired in the above order, by the new gun worked by three men, was 7′ 44″. The time in which the same was performed with the old gun, worked by six men, was 9′ 9″.

No. 4. The guns were each fired eight rounds double shotted. The old gun kicked up, shook the deck, and displaced its

quoin. The new gun did not kick up, nor shake the deck, nor displace its quoin.

No. 5. The new gun was pointed steadily at its object, by moving the breast block, and was fired while in the act of being pointed.

This was done most satisfactorily; the men, when traversing the gun, being perfectly clear of the recoil.

No. 6. The guns were pointed at the greatest angle of elevation and depression which their ports (of similar height) would admit of. In the new gun, the angle of the elevation was 14° 45′; the angle of depression was 13° 30′. In the old gun, the angle of elevation was 12° 15′, of depression was 7° 15′.

No. 7. The new gun by its crew (three men) was placed upon its transporting truck in 57″, and remounted upon the breast block in 40″.

No. 8. The breech carriage was taken away by three men in 43″, and replaced by the same in 24″.

No. 9. The breast block was removed from the gun in 1′ 2″, and replaced by three men in 1′ 10″.

These experiments, together with other documents respecting the carriages, were signed by Captains J. T. Maling, C. R. Moorsom, and H. Patton, who were appointed by the Commander-in-Chief at Chatham, to inspect, and report on Capt. Marshall's carriage. There are several other highly satisfactory reports appended to Captain Marshall's book.

In reference to the qualifications we have enumerated, as desirable in a carriage for ship artillery, we must observe that Captain Marshall gives the weight 8 cwt., as the weight of the two carriages on his principle, which are to replace the old gun-carriage of 7 cwt., but he observes that as "no experiments have yet been made to show the strength which is necessary in the parts of the new carriage; they have probably been made heavier than experience may show to be requisite." We are doubtful whether the new gun-carriage would not be found to be more easily put out of order if struck by a shot, than the old carriage; but it is evident, from the report of the experiments, that such a casualty may be far more easily remedied in Captain Marshall's system than in the present. The work-

manship of the new carriage would be more expensive than that of the old, but this cannot be considered as a valid objection, if it produces compensating advantage, which must be the case if it should enable any reduction to be made in the crews of ships. There is another objection which appears to us may require attention, which is, that in continued firing, the breeching and breast rope may be so stretched, that the muzzle may, in the recoiling, over-run the crutch, in which case the gun would fall on the deck; however, little care would suffice to guard against this inconvenience; and, indeed, none of the reports contained in the book, on the firing of the gun, notice this effect as likely to occur. The principle on which Captain Marshall proposes to mount ship artillery, appears to possess such numerous advantages, that we are glad to find it is the intention of Government to institute an experiment on a large scale for the purpose of fully deciding on the fitness of his carriage for His Majesty's service.

Art. XVI.—*Account of finding the Centre of Gravity of His Majesty's Ship Scylla, of* 18 *guns, by Experiment.*[1]

When the Scylla, a ship-sloop, formerly a brig, was lying in Portsmouth harbour, nearly fitted and ready for sea, its centre of gravity was found by experiment in the following manner, 7th May, 1830. The method used was nearly similar to that which Chapman used in finding the centres of gravity of Swedish ships; only substituting the correct moment of stability, instead of the moment of stability calculated by the metacentre. See Art. 3. Vol. I. of this work.

The draught of water was taken very correctly, the water being smooth.

	ft.	in.
Forward - - - - -	11	6
Abaft - - - - - -	14	$10\frac{1}{2}$

The depth of the keel and false keels below the lower edge of the rabbet of the keel was:

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[1] The experiment was made by Captain Hindmarsh and Mr. Morgan.

	ft.	in.
Forward - - - - -	1	9
Abaft - - - - - -	1	3

The ship was perfectly upright, all the weights being equally balanced on each side. A large quadrant marked with degrees, with a plumb attached to the centre, was fixed in the main hatchway. The situations of the carronades and long gun on one side were marked on the deck. They were then moved to the other side, keeping them in the same transverse lines; the shot and hammocks were also carried over to the inclined side, and the crew, which were first equally divided on each side of the ship, were all placed on the same side. The distance which every weight had been moved was then measured. The weight of every article moved was known: the weights of the carronades and gun were marked on them, and the weight of the men and hammocks were obtained by weighing them. The inclination of the ship was then observed to be 6° 20′. The carronades, shot, &c. were then replaced.

The weights of the carronades, shot, &c. in tons, multiplied into the distances, moved in a transverse direction, in feet= 264,5. This moment multiplied into the cosine of the angle of inclination, is equal to the moment of the stability of the ship.

Let D = the displacement of the ship in tons, A = the volume immersed by the inclination in tons, b = the distance between the volumes immersed and emerged by the inclination, d = the distance between the centres of gravity of the displacement and the ship.

$$\text{Then } b\,\mathrm{A} - d\,\mathrm{D}.\ \sin.\ 6^\circ\ 20' = 264,5.\ \cos.\ 6^\circ\ 20'$$

$$d = \frac{b\,\mathrm{A} - 264{,}5\ \cos.\ 6^\circ\ 20'}{\sin.\ 6^\circ\ 20'\ \mathrm{D}}$$

By substituting the values of b, A, and D, obtained by calculation, in this expression, the value of d, the distance between the centre of gravity of the displacement and the centre of gravity of the ship is obtained.

$$d = \frac{446{,}2 - 262{,}8}{50{,}85} = 3{,}6 \text{ feet.}$$

The distance of the centre of gravity of the displacement below the load-water line = 3,97 feet.

3,97 − 3,6 = ,37 the distance of the centre of gravity of the ship below the load-water line at the time of the experiment.

When the ship was at Spithead, with every thing on board, which was deficient at the time of the experiment, and provisioned and stored for four months, the draught of water was again taken.

	ft.	in.
Forward - - - -	12	6
Abaft - - - - - -	14	10

The weight of all the articles brought on board since the experiment was 33,4 tons, and the moment of these weights calculated above the water-line, at the time of sailing was = 193 tons; the height of the centre of gravity of the sails being estimated as in the case of a top-gallant breeze.

The moment of weights below this water-line at the time of experiment = 401 tons.

$$\frac{401-193}{494,4} = ,42 \text{ ft.}$$

The situation of the centre of gravity of the ship was ,42 foot, or 5 inches, below the water-line at the time of sailing.

Art. XVII.—*A List of the Patents which have been taken out since the* 1*st of January,* 1830, *for Inventions or Improvements connected with Naval Affairs; with extracts of Specifications, &c.*

To William Hall, of Colchester, in the county of Essex, machinist, for a machine or method of raising or forcing water for propelling vessels. Dated January 12th, 1830.

To John Revere, of New York, in the United States of America, now residing in the parish of St. James, Westminster, M.D., for a new alloy, or compound metal, applicable to the sheathing of ships, and various other useful purposes. Dated January 28th, 1830.

To John Gray, of Beaumorris, in the county of Anglesea, gentleman, for a new and improved method of preparing and

putting on copper sheathing for shipping. Dated February 4th, 1830.

To Robert William Sievier, of Southampton-row, Russell-square, in the parish of St. George's, Bloomsbury, in the county of Middlesex, sculptor, for certain improvements in the construction of rudders for navigating vessels. Dated February 27th, 1830.

To Philip Chilwell de la Garde, of the city of Exeter, gentleman, for certain improvements in apparatus for fidding and unfidding masts, and in masting and rigging of vessels. Dated February 27th, 1830.

To James Ramsay and Andrew Ramsay, both of Greenock, in North Britain, cordage and sail-cloth manufacturers; and Matthew Orr, of Greenock, aforesaid, sail-maker; for an improvement in the manufacture of canvas and sail-cloth for the making of sails. Dated March 20th, 1830.

To George Scott, of Water-lane, in the city of London, engineer, for certain improvements on, or additions to, windlasses and relative machinery applicable to naval purposes. Dated March 20, 1830.

To William Alltoft Summers, of Saint George's-place, Saint George's in the East, in the county of Middlesex, engineer; and Nathaniel Ogle, of Millbrook, in the county of Hants, esq.; for certain improvements in the construction of steam engine and other boilers, or generators, applicable to propelling vessels, locomotive carriages, and other purposes. Dated April 13th, 1830.

To Thomas Cook, of Blackheath-road, in the county of Kent, lieutenant in our royal navy, for certain improvements in the construction and fitting-up of boats of various descriptions. Dated April 24th, 1830.

Extracts from Specifications, and Remarks.

Extracts from the Specification of Lieut. William Rodger's Improvements in the Construction of Anchors.—My said invention of certain improvements, in the construction of anchors, partly consists in improvements upon a former patent, taken out by me on the 13th day of March, in the year 1828, for certain improvements on anchors, and which said improve-

ments are the result of experiments, made by me with a view to determine the best and strongest forms which could be given to anchors made upon the principle of my said patent. Thus I have found it advisable in order to give additional strength to the shanks of anchors formed of combinations of wood and iron, to alter the form of the iron plates of which the shanks are constructed, and to introduce several additional plates as will be herein-after described, and to combine them together, with or without the interposition of a central piece or core of wood, and which central piece is only used to facilitate the operation of combining them, and not with a view of giving an additional strength to the shanks; but which also will prevent so much water from entering, as would be the case if the shank were left hollow. The whole is to be bound together by means of iron bands or hoops, in place of bolts or pins and hoops, as in my former patent above-mentioned. And likewise in order to strengthen the arms or flukes, I have adopted another method of connecting or uniting them to the iron plates of which the shanks are formed, as is also herein-after described.

Fig. 53 is a side view of an anchor formed upon my last improved construction; and Fig. 54, a plan of the same.

Another of my said improvements in the construction of anchors, consists in a new method of affixing the stocks upon the shank of the anchor, and which I effect in the following manner. In Fig. 54, the stock U U is shown in the plan, as being affixed to the anchor. Fig. 55, is a top view of the stock, ready for affixing upon the shank of an anchor; and which stock may be made either of one or two pieces of timber, as may be most convenient. It is however to be observed that the stock is to be completed before affixing it upon the shank, and which said affixing is done in the following manner:—After the stock is shaped, a hole V, shown in Fig. 55, is to be made through the centre of it, to fit that part of the shank upon which it is to be affixed. Two stock plates, one of which is shown by a top view of it, in Fig. 55, are then to be placed, one on each side of the stock, and let in nearly flush therewith, and secured by means of countersink headed nails, and two bands or hoops, W, W, as shown in Fig. 55. Middle and end hoops are also

to be fitted upon the stock as usual. In place of nuts formed upon the shank of an anchor, in order to secure the stock in its place, I use a hoop X, Figs. 53 and 54, which is so situated upon the shank as to prevent the stock from going nearer to the crown of the anchor than it ought to do; and upon this hoop X, the stock rests, and is prevented from sliding towards the shackle of the anchor, by means of the fore-lock key Y, Fig. 54, which is passed through a hole K, made in the shank for that purpose, and as before described, and as shown in Fig. 53. Previous however to putting in the fore-lock key, the oval ring or collar Z, shown in Fig. 53, is to be placed on the shank as shown in Figs. 53 and 54. As fitting the stock to the shank of an anchor by this method, prevents the use of a ring as in the ordinary manner, I, in all cases, substitute a shackle for the ring; and which is all that is required for a chain cable; but when a hempen cable is to be used, I connect a ring *a* to to the usual shackle, by means of a joining shackle, as shown in Figs. 53 and 54. This however I do not mention as a new invention, having already employed it with an anchor of a different construction, and for which I obtained a patent in the month of December in the year 1819.

Observations communicated by the Patentee.—The intention is to combine in this patent anchor the good properties of the old long-shanked anchor, together with the important advantage of great additional strength. It is the same length as the old established anchor, but nevertheless it has been proved by numerous experiments to be much stronger than the common short-shanked one, and is therefore in every respect suitable for chain cables. It would be superfluous to enlarge on the superiority of a long-shanked anchor, as it is admitted by every experienced seaman, that the old anchor, which is still used with hempen cables, holds much better than that with a short shank which has come into use since the introduction of chains; but unfortunately it is not sufficiently strong. The great increase of strength in the patent anchor is owing to the peculiar formation of the shank, which consists of six pieces of iron, of such a thickness, that there is a certainty of making them perfectly sound for anchors of the largest dimensions.

The two principal pieces, AA, Fig. 53, are bent so as to form a part of the arms or flukes; the other four are formed into a hollow square frame or tube HH, for a centre-piece, and the whole are firmly welded together at both ends of the shank. Figs. 56 and 57 are enlarged sections of the shank at the dotted lines S, S. The intermediate parts are secured by means of strong hoops, so that every piece must bear a proportionate strain. Such in fact is its strength, that both arms have been broken off, by means of the testing machine, without altering the shank in the slightest degree. On the 11th June, 1829, an experiment was made at Gateshead Iron Works, in the presence of several respectable ship-owners, when the patent anchor, weighing 9 cwt. 1 qr. 4 lbs. broke, in succession, the following anchors, on the old construction, without receiving the least injury, viz. one of 10 cwt. 3 qrs. 4 lbs. for hempen cable; one of 10 cwt. 2 qrs. 12 lbs.; and one of 12 cwt. 4 lb. for chain cables.

The plan by which the patent anchor may be stocked or unstocked in a few minutes, without the assistance of a carpenter, will no doubt be considered a strong recommendation, as a considerable length of time is required to stock an anchor in the usual way with a wooden stock.

These plans have been examined by many eminent engineers, amongst whom are Messrs Maudslay, Fulton, Seaward, Le Marchant, and Bramah; from whom, and from numerous other gentlemen in every way competent to judge of their merits, I have received highly satisfactory certificates. I am also happy to say that the Navy Board has just ordered an anchor for a 46-gun frigate, to be constructed on my plan, at Woolwich; and there are several in use on board coasters belonging to Newcastle, Shields, and Waterford; and in all cases I have received the most favourable accounts of their holding power.

Extract from Mr. John Gray's Specification of an improved Method of Coppering Ships' Bottoms.—My improved method of preparing and putting on copper sheathing for shipping, consists in piercing nail-holes through the copper sheathing (in a particular manner hereinafter to be described) in order to receive the nails by which the copper sheathing is to

be fastened to the bottom of the ship; those nail-holes being disposed in rows at regular distances apart, along one side and across one end of the border of each sheet, and other holes being dispersed over the middle part of that side of the copper which is to be outwards when it is put on the ship) by causing such a depression of the copper around each of the nail-holes as will form suitable countersinks to receive the heads of the nails by which the copper is to be fastened to the bottom of the ship; the same depression of the copper, from the outside also, making a prominence around each nail-hole at the inside surface, which is to be applied to the bottom of the ship; and those prominences, by entering into the surface against which the copper is applied, will cause it to adhere more firmly. That portion of the copper around each nail-hole, which is so depressed from the outside and rendered prominent at the inside, being hardened by the pressure given to it between hard steel surfaces in the operation of piercing the said nail-holes, which operation I perform by one or other of two simple machines.

Observations communicated by the Patentee.—The advantages proposed to be gained by the new mode are as follows:—1. The ship's bottom has a perfectly even surface by the nail-heads (of the ordinary sort) being quite buried to the exact level of the sheet, consequently there is no interruption at all to the progress of the vessel; and should she become foul from lying long in harbour or otherwise, she may easily be hogged without the risk of drawing a single nail. 2. In the ordinary mode, the countersunk nail-heads have a projection beyond the surface of the sheet, consequently this causes a play of eddy water round it, and the copper thereby becomes the quicker destroyed, as may be observed in old sheathing on those particular spots. 3. The sheathing is, beyond comparison, more strongly fixed than in the common method, because both the over as well as the under lapping sheets, must be forced into the plank, by the cavity formed on the upper sheet for receiving the countersunk part of the nail, which thus completes the even surface of the whole.

PAPERS

ON

NAVAL ARCHITECTURE,

&c.

Art. XVIII.—*Chapman's Work on Ships of War, translated from the Swedish, by* Wm. Morgan, *of His Majesty's Dock-yard at Sheerness.*—(Continued from page 166.)

Chap. IV.—*Shows the Manner of making the Construction-element, so that the direction of the diagonals which form the Ship's after-body may agree with the relaxation-line.*

12. When the length, l, of the ship at the water-line, and the breadth, B, are known from the displacement by the method just described, the next step is to find the depth of the construction-element and the form which the ship should have in the water, that its centre of gravity may be properly situated longitudinally, and that the relaxation-line may at the same time, as far as possible, be applied in the formation of the ship's after-body.

This cannot be determined without much investigation, because a ship's quarters, whose fulness is detrimental to the well-sailing of a ship, depend on the proper application of this line; and as the largest ship should necessarily have the fullest quarters, it is requisite to adopt those of a ship of 110 guns in this investigation, whose fulness abaft is diminished as much as so great a body and upper works can admit, without losing too much of its bearing at that part.

As the relaxation-line should be as nearly as possible perpendicular to the curvilinear form of the sections: that is, the middle or construction-diagonal EI (Fig. 68), as well

as the other diagonals on the after body-plan, as far as circumstances permit, should be placed at right angles to the contour of the sections; it is found, that for all line-of-battle ships, it must make an angle, *F E I*, of 27° 9′, with the vertical line.

It must be observed, that the length l is the construction-length of the ship's body at the water-line, and is also the true length of the water-line, when the rake of the stem is inconsiderable; but if it is great, the true length of the water-line between the rabbets of the stem and sternpost must be increased forward by a quantity $= \frac{l}{119}$, that the bow constructed according to the proposed method may obtain its proper form. Thus the whole length of the water-line between the rabbets of the stem and sternpost is $= \frac{120}{119}\, l$.

Let L express the length of the upper water-line between the rabbets; draw the line $A\,C = \frac{1}{2}\, L$ (Fig. 58), from C draw the perpendicular line $C\,D$, produced; and let radius : tangent of 13° 17′ :: $A\,C$: $C\,a$, and draw $A\,a$, then $A\,a$ is the direction of the relaxation-line, when the water is supposed to glide along the said diagonal, inclined at an angle of 27° 9′ to the vertical line in the body-plan.

Nevertheless, as the intended method of construction requires that its direction should be shown, when it is viewed perpendicularly to a vertical line, then rad. : cos. 27° 9′ :: $C\,a$: $C\,b$; draw $A\,b$, then $A\,b$ is the direction of the relaxation-line, which makes an angle of 11° 52′, when it is seen in a vertical direction; and this is the direction which the diagonals of the sections should have. But as a ship straightens immediately it is launched; that is, its extremities drop, by which its sheer is straightened, which may be taken at $\frac{1}{400}$ part of the length of the ship at the water-line, and the contrary curve it then assumes may be considered to be a parabola, whose exponent is 1,6, when the subtangent is $\frac{1}{250}$ part of the same length; this tangent then makes an angle of 30′ with the former line of the ship. When this is added to 11° 52′, the angle $C\,A\,d$ is 12° 22′; hence $A\,d$ is the direction of the relaxation-line, when it is viewed perpendicularly to a vertical line, and is the basis for the areas of the sections. But to obtain it in the direc-

tion of the diagonal line $E\,I$ (Fig. 68), $\frac{\text{rad. tang. } 12° \, 22'}{\text{cos. } 27° \, 9}$ = tang. 13° 51′ = the angle $C\,A\,f$.

As the true line or construction-diagonal on the sheer draught differs but little from the line of sections, it is considered quite unnecessary to diminish the angle of the direction of the line of sections which should afterwards be set off from the true line.

13. When a ship's body is to be formed with a given displacement, the length, breadth, and draught of water being also given, it is evident, that the fuller the ⊕ section is made, the sharper will be the extremities; and conversely.

As the dimensions of a ship of the line are less in proportion to its displacement, than those of smaller vessels, the ⊕ section of a ship of the line should be greater in proportion to its dimensions; but in order to diminish the effect of the water abaft, which impedes its progress, and therefore to diminish the quarters, the ⊕ section should be placed further forward: and as the after part is thence sharp, the displacement would be obtained by a full fore body, by which the centre of gravity of the displacement would come too far forward, which causes not only pitching in a swell, but also dipping forward under sail, by which the ship loses in its course and in readiness of coming about. It thus becomes the object to give a proportionably full ⊕ section, which admits of continuing the flatness, without having too full quarters, and at the same time does not cause the centre of gravity to come so far forward.

As it is the object, to give to all ships of the line the form abaft which will conduce to their good sailing, which is effected by the application of the relaxation-line, it has been found most proper, to suppose at first, that the construction-element of ships of the line (as was mentioned in § 11) should consist of two parts, one above the other. The upper edge of the lower element is supposed to coincide with the water's surface $A\,B$ (Fig. 60) and its after end, A, to be terminated by the relaxation-line, $A\,F$; the upper element is a parallelopiped of the same breadth as the lower and nearly the same length $X\,Q$, and of such a depth $X\,Y$, that its solid content, together with that of the lower element, may comprise the whole displacement; both toge-

ther being regarded as one body or element $AYXQLRHA$. It is understood that it is the upper side XQ of the parallelopiped which now lies on a level with the water line,—that this body has the same breadth as the ⊕ section,—that the breadth continues parallel from one end to the other,—and that the ordinates MF, UK, OV, &c. (Fig. 61) are such, that when they are multiplied by the breadth of the body, these rectangles express the areas of the sections; consequently, the greater UK or TD is, the greater is the area of the ⊕ section.

It has at length been found by much investigation, in respect to the application of the relaxation-line abaft, 1. that the ship ought to have two ⊕ sections, the one TD at the middle of AB, and the other UK at a distance DK before it $= \frac{L}{16,5} = a$, and, 2. that the depth of the lower part IK is to be $= \frac{l}{12,974} = \mathbf{h}$.

Chap. V.—*To form the Construction-element of a Ship of* 110 *guns.*

14. Its displacement $= 152875$, length, $l = 207,59 = AL$, $\frac{l}{119} = 1,74 = f = LB$, hence $L = 209,33$, $\mathbf{h} = \frac{l}{12,974} = CD = IK = 16,0$, $B = 56,27$.

Let C be the middle of the line AB (Fig. 58 and 59). From this point draw the vertical line CD (Fig. 58) produced; from C set off $CD = 16,0 = \mathbf{h}$, and from the point D draw the line DE parallel to AC, then the lines DE and Ad cut each other in E. From E take $EF = ED$, and draw FD; from the middle point G of this line, draw GE; let $FG = GD$ be the ordinate, and GE the subtangent to a parabola, whose exponent $= 1,68$ (in all parabolas the abscissa $=$ the subtangent divided by the exponent), the abscissa is then obtained $= GH$, by which the parabola is easily described.

In this manner the section-line $AFHD$ is obtained abaft the after ⊕ section. It is called the section-line, because it is the foundation of the areas of the sections. From D set off

the distance DK (Fig 59) $= \frac{L}{16,5} = a = 12,687$, and draw KI, then KI is the foremost ⊕ section.

Divide the distance $CA = 104,66$ (Fig. 58) into ten equal parts, 1, 2, 3, 4, 5, 6, 7, 8, 9, and draw lines perpendicular to AC, then these are the stations of the sections, and likewise the ordinate between the line AC and the line $AFHD$: this figure will be general, not only for ships of the line, but also for frigates, when the relaxation-lines are used; but as the equation cannot yet be given, the lengths of the ordinates, called h, are taken in feet by scale, and inserted in the following table: and when **h**, the ordinate of the ⊕ section for the same ship or frigate, is multiplied by the number in the column E, the lengths h of all the ordinates 1, 2, 3, 4, &c. are known.

Ordinates.	Lengths h of the ordinates of a ship of 110 guns.	All the ordinates h of the sections, divided by the ordinate **h** of the ⊕ section.
		E.
⊕	16,00	1,00000
1	15,89	0,99312
2	15,50	0,96875
3	14,66	0,91626
4	13,20	0,82500
5	11,33	0,70813
6	9,19	0,57434
7	6,90	0,43125
8	4,61	0,28812
9	2,31	0,14438
10	0,00	0,00000

The distance between these ordinates = [illegible], and the area of the space $ACDHFA = 1065,31$, also [illegible]s centre of gravity S from the line $CD = 37,51 = MS$; the area between

the two ⊕ sections CD, IK, $= 203{,}2$ (Fig. 59), which, together with $1065{,}31 = 1268{,}51 = \frac{\overline{\frac{1}{2}L + a}\,.\,\mathbf{h}}{1{,}4802}$, their common centre of gravity O, abaft the after ⊕ section or line $CD = 30{,}5 = MO$; but the same centre of gravity is abaft the foremost ⊕ section $= 43{,}175 = ZO = \frac{\frac{1}{2}L + a}{2{,}718}$. Let the centre of gravity of the whole plane $ALRKHA$ be situated at $N = 4{,}4$ feet from the after section or CD, then $NO = 30{,}5 + 4{,}4 = 34{,}9$, which multiplied by $1268{,}5 = 44270 = M$, the after moment.

Suppose that KRL, the foremost end of the element, is a parabola, the vertex in K, the absoissa $KI = \mathbf{h} = 16$, and the ordinate $IL = s = 90{,}238$. It now becomes necessary, to find the exponent n of this parabola, that the moment of the parabolic space $KRLIK$ from the common centre of gravity N may be $=$ the moment M of all the remaining part from the same centre of gravity N.

From N to the ⊕ section $KI = 12{,}687 - 4{,}4 = 8{,}3 = p$, consequently the moment $M = p + \frac{\overline{n+1}\,.\,s}{2n+4} \,.\, \frac{n s \mathbf{h}}{n+1}$ hence $\overline{2n+4}\,.\,\overline{n+1}\,.\,M = \overline{2n+4}\,.\,n s \mathbf{h} p + \overline{n+1}\,.\,n s^2 \mathbf{h}$. Let $p s \mathbf{h} = Q$, and $s^2 \mathbf{h} = R$, then is $2n^2 M + 6nM + 4M = 2n^2 Q + 4nQ + n^2 R + nR$, whence
$2n^2 Q + n^2 R - 2n^2 M + 4nQ + nR - 6nM = 4M$; put $2Q + R - 2M = S$, and $4Q + R - 6M = T$, then $n^2 - \frac{nT}{S} + \frac{T^2}{4S^2} = \frac{T^2}{4S^2} + \frac{4M}{S}$, whence $n - \frac{T}{2S} = \frac{\sqrt{16SM + T^2}}{2S}$ and finally $n = \frac{\sqrt{16SM + T^2} + T}{2S}$. When all the proper values are inserted in the expression, the exponent $n = 2{,}432$, which answers for all ships of the line; hence $\frac{n s \mathbf{h}}{n+1} = \frac{2{,}432\,.\,90{,}238\,.\,16}{3{,}432} = 1023{,}1 =$ the area before the foremost ⊕ section. When the part abaft $= 1268{,}5$ is added to it, the area of the whole figure or lower element $ALRKHA$ is $= 2291{,}6 = \frac{l\,\mathbf{h}}{1.4494} = A$, which is the

lower element for all ships of the line. The displacement 152875 divided by the breadth 56,27 $= \frac{D}{B} = 2716,8$; when 2291,6 is subtracted from this quantity, there remains $425,2 = \frac{D}{B} - A$, which is equal to the length of the parallelopiped multiplied into its depth, by which this lower element will be increased.

15. As the ship has fine quarters, the lower element is also diminished abaft, by which the displacement is decreased; the parallelopiped will therefore be made so much the shorter accordingly; and it has been found, that the quantity by which it is shortened, AY, (Fig. 60) may be $= \frac{l}{33,26} = g = 6,24$. If the height AW is put $= e$, and the whole after part of the element is tapered in such a manner that the area of the curvilinear triangle $WAgW$ (Fig. 62) is equal to the area of the rectangle $WY = g \,.\, e$, then nothing is lost in the displacement. The area of the rectangle of the parallelopiped, or the length of the body $XQ = l - g$ (Fig. 60) multiplied by the height $XY = AW$, is $= \overline{l - g} \,.\, e = 201,35 \,.\, e = 425,2$, hence $e = 2,112$; when $16 = \mathbf{h}$, is added to this quantity, the whole depth of the body at the ⊕ section $= 18,112 = TD = \mathbf{k}$, which multiplied by $B = 56,27 \,.\, 18,112 = 1019,20 =$ the area of the ⊕ section.

As the lower element from the foremost ⊕ section forward is formed by a parabola, the same end of the whole element will also be formed by a parabola, whose ordinate s, abscissa $\mathbf{k}$, and exponent m, are found in table No. 15, by which it is easily calculated and drawn, as KVQ; but it is continued to the rabbet of the stem, as kS. The ordinates of this line, called k, multiplied by the breadth, B, give the areas of the sections of the fore body.

When all the vertical ordinates of the plane $WgFHDKVkSW$ are multiplied by the greatest breadth, B, of the body or ship, the areas of the transverse sections are obtained, and thence the element, whose solidity is equal to the displacement of the ship, and whose centre of gravity is before the middle a distance $= a - p$. See the last line of the table just mentioned.

The reason why the parabola is used in forming the fore part of the ship is this: when the areas of the foremost sections have been calculated from the draughts of many well-built ships, and these areas have been divided by the greatest breadth of the ship at the water-line, a curve line has been accordingly described, which nearly coincides with a parabola, the vertex being at the ⊕ section, and the ordinates drawn from the upper water-line, whose exponent is higher or lower as the ship is fuller or sharper. The parabola has never reached to the rabbet of the stem by a foot, or nearly a foot and a half, without being given at the foremost end a contrary flexure, on account of the rake of the stem.

The construction-element of a ship is at length obtained of the same magnitude as its displacement, whose length is equal to the length of the ship at the water-line, and whose breadth is equal to the breadth of the ship at the water-line in midships, and of such a form, that the areas of all the sections, ⊕, 1, 2, 3, &c. are equal to the areas of the sections of the ship at the corresponding stations; consequently, the centre of gravity of this element is situated longitudinally at the same place as the centre of gravity of the ship. This will be best understood by reference to the following table No. 15.

In this table every thing is found which is necessary to commence with the drawings, after the rake of sternpost and curve of the stem are determined.

TABLE No. 15.

The Calculations for all the Ships are collected together in this Table.

	110	94	80	74	66	52
Displacement to the outside of timbers (Tab. 11) = D	152875	128297	107400	96422	88722	66753
Greatest breadth at the water-line (§ 10) = B	56,27	53,32	50,92	49,51	48,46	45,00
Length of construction-water-line (§ 10) = l	207,59	196,65	186,15	180,05	175,48	166,00 [1]
Increase of this water-line forward = $\frac{l}{119} = f$	1,74	1,65	1,56	1,51	1,47	1,39
Whole length of water-line = $l + f = L$	209,33	198,30	187,71	181,56	176,96	167,39
Height of the figure $\frac{l}{12,974} = \mathbf{h}$	16,00	15,157	14,348	13,878	13,526	12,795
Displacement divided by the breadth = $\frac{D}{B}$	2716,8	2406,2	2109,2	1947,53	1830,83	1483,4
Whole area of the figure $A\ B\ G\ A$ = $\frac{l\,h}{1,4494} = \frac{l^2}{1,4494\,.\,12,9744} = \frac{l^2}{18,805} = A$	2291,6	2056,4	1842,7	1723,9	1637,5	1465,4
Area of the rectangle $\frac{D}{B} - A$	425,2	349,8	266,5	223,63	193,33	18,00
Diminution of length of rectangle abaft = g........	6,24	5,4	4,77	4,31	4,04	2,00

[1] In the double frigate the length l has been increased 5,28 feet, to make it a little sharper at the extremities; and the length L = 167,39 has been increased abaft 0,5 foot, so that the whole length of the water-line is 167,89.

TABLE No. 15—(*continued*).

	110	94	80	74	66	52
Whole length of the rectangle $= l - g$	201,35	191,25	181,38	175,74	171,44	164,00
Height of the rectangle $\frac{\frac{D}{B} - A}{l - g} = e$	2,112	1,829	1,469	1,273	1,128	0,110
Height $\mathbf{h} + e$, the depth of the construction element at the $\oplus$ section $= \mathbf{k}$	18,112	16,986	15,817	15,151	14,654	12,905
Area of the $\oplus$ section $B \cdot \mathbf{k} = \oplus$	1019,20	905,69	805,40	750,13	710,13	580,72
Distance between the two $\oplus$ sections $= \frac{L}{16,5} = a$	12,687	12,018	11,377	11,004	10,724	10,145
Length $a + f$	14,427	13,668	12,937	12,514	12,194	11,535
Length $\frac{L}{2}$	104,665	99,150	93,855	90,780	88,475	83,695
Length $\frac{L}{2} - \overline{a + f} = s$	90,238	85,482	80,918	78,266	76,281	72,160
Exponent for fore part $F = n$	2,432	2,432	2,432	2,432	2,432	2,432
Area $\frac{n\, s\, \mathbf{h}}{n + 1} = F$	1023,10	918,13	822,72	769,69	731,15	654,26
Area of the rectangle $s \cdot e$	190,60	156,35	118,87	99,63	86,04	7,94
Whole area forward $= F + s \cdot e = R$	1213,70	1074,48	941,59	869,32	817,19	662,20
Product $= s \cdot \mathbf{k}$	1634,40	1452,00	1279,90	1185,80	1117,80	931,23
$\frac{R}{s\,\mathbf{k} - R}$ = exponent $= m$	2,8850	2,8462	2,7832	2,7468	2,7184	2,4614

TABLE No. 15—(*continued*).

	110	94	80	74	66	52
Proba. area forward $= \dfrac{m\,s\,\mathbf{k}}{m+1} = R$	1213,70	1074,48	941,59	869,32	817,19	662,20
Centre of gr. before foremost ⊕ section $= \dfrac{\overline{m+1}\,.\,s}{2m+4} = q =$	35,884	33,921	32,000	30,889	30,057	27,993
Moment $\dfrac{m\,s^2\mathbf{k}}{2m+4}$ or q R	43553	36448	30131	26852	24562	18537
Area abaft foremost ⊕ section $= \dfrac{\overline{\tfrac{1}{2}L+a}\,.\,\mathbf{h}}{1,4802} = E$	1268,5	1138,3	1020,0	954,3	906,48	811,15
Centre of gravity abaft foremost ⊕ section $= \dfrac{\tfrac{1}{2}L+a}{2,718} = r$	43,175	40,901	38,717	37,448	36,497	34,525
Moment abaft $= r\,E$	54768	46559	39493	35737	33084	28006
Length of rectangle abaft foremost ⊕ section $= \tfrac{1}{2}L + u - g = t$	111,112	105,768	100,462	97,474	95,159	91,840
Area of rectangle $t\,.\,e = G$	234,67	193,45	147,58	124,09	107,34	10,102
Its moment abaft foremost ⊕ section $= \dfrac{t^2 l}{2} = N$	13039	10230	7413	6047	5107	464
Moment $r\,.\,E + N - q\,R$	24254	20341	16775	14932	13629	9933
Area of the whole figure $= E + G + R$	2716,8	2406,2	2109,2	1947,7	1831,0	1483,4
$\dfrac{r\,.\,E+N-q\,R}{E+G+R}$ = centre of gravity abaft foremost ⊕ section $= p$	8,927	8,454	7,953	7,666	7,443	6,696
Common centre of gravity before the middle of the water-line $L = a - p$	3,760	3,564	3,424	3,338	3,281	3,449

16. *On the stem and sternpost.* The stem has the rake, which is shown on the draught, for this reason: that the bow may have a sufficient flare above, to throw off the sea at the sides, which rises against it in consequence of the ship's way. The stem, being very straight at the lower end, is morticed into the keel like the sternpost, and is secured to the keel in the same manner; and as this method is stronger than any other, it must be the best. See the sheer-draught of a ship of 74 guns, plate V. *A*. It is constructed for all ships of the line in the following manner:

The foremost end of the water-line is the after-part of the rabbet of the stem. Set off from this place on the water-line produced, a distance of five feet, and through this point draw a line at right-angles to the water-line, both above and below it; set off on this perpendicular above the water-line a distance of 25 feet, and through this point draw a line parallel to the water-line; then this point is the vertex, and this line the axis, of a conic parabola, whose abscissa $x = 5$, and ordinate $y = 25$, consequently $x = \frac{y^2}{125}$. Draw this parabolic line from the vertex to the keel.

The position of the bowsprit determines the height of the stem above the water-line, and the distance of the keel below the water-line determines the lower end of the stem. This is better seen in the draught.

The sternpost. The after end of the water-line is the fore side of the rabbet of the sternpost, and its rake $= 6^{0}\ 25'$.

The sheers of the deck, wale and height of breadth line, are as shown on the draughts. The height of the transom determines itself.

CHAP. VI.—*To form the Load-water Section, and the Plan of the half-breadth Line.*

17. In forming the load-water section the following considerations must be attended to:—

When a body whose specific gravity is less than that of water, is wholly immersed therein, it is immediately raised

by the force of the water so much above the water's surface, that the part left below the surface displaces a volume of water equal to the body's weight; and the whole force of the water to counteract any force which tends to change the position of a body lying at rest in the water, is greatest at the water's surface. It is also known by a common rule, that the power of the water to preserve a body in its horizontal position, is as the length of the body multiplied into the cube of its breadth at the surface of the water; thus the force is greatest at the surface of the water; consequently, the greater the extent of the water-section of the body, the greater is the force of the water to preserve it in its quiescent state; therefore the water's surface is the basis or foundation for all bodies floating on the water.

The load-water section is thus the most important element in the whole construction, because the stability of a ship depends principally on it; consequently, all calculations which concern either the part below or above this basis, must be made from the water's surface, or the water-line.

As the length and breadth of the load-water section are given for all the five line-of-battle ships, it is its form for each ship which remains to be found. And as each end of this section will require a different construction, the part from the foremost ⊕ section to the stem will be given first.

18. *To construct the part of the load-water section before the foremost ⊕ section.*

Let CA (Fig. 63) be the middle line of the ship. $CT = AB =$ the greatest half-breadth of the water-line. Draw TB. Let CA be the distance from the foremost ⊕ section to the stem, and divide this distance into 10 equal parts.

As the side of the ship between the two ⊕ sections is straight, and this straightness should not continue further, the breadth of the water-line is diminished $\frac{1}{200}$ part, IT. Draw the line IK parallel to CA, and put this diminished half-breadth $= a$, which increases from the section No. 4, till it again resumes its full breadth at the ⊕ section.

TABLE No. 16.

		94	80	74	66
Half-breadth.... $\frac{1}{2}B$......	28,135	26,66	25,46	24,755	24,23
$\frac{1}{2}B - \frac{\frac{1}{2}B}{200} = CI = a$....	27,994	26,53	25,33	24,631	24,11

It is found that the water-line for a ship of 110 and a ship of 74 guns, is properly formed, when its breadth EG at the 7th division from the foremost ⊕ section to the stem is $24{,}4 = c$ for a ship of 110 guns, and $21{,}02 = c$ for a ship of 74 guns; and when the breadth of the generating parabola, according to which the outer line is constructed, for the same place is $= 23{,}1 = \mathrm{b} = EH$, and $19{,}99 = b$; whence c and b, at the 7th division (for all the five ships), are known by the following rule:—When the exponent is put $= v$,

$$\frac{\log.\ \mathrm{c} - \log.\ c}{\log.\ \mathrm{a} - \log.\ a} = \frac{\log.\ 24{,}4 - \log.\ 21{,}02}{\log.\ 27{,}994 - \log.\ 24{,}631} = 1{,}165,$$

whence $c = \frac{\mathrm{a}^{1{,}165}}{1{,}9881}$. The exponent v of the parabola is =

$$\frac{\log.\ \mathrm{b} - \log.\ b}{\log.\ \mathrm{a} - \log.\ a} = \frac{\log.\ 23{,}1 - \log.\ 19{,}99}{\log.\ 27{,}994 - \log.\ 24{,}631} = 1{,}13,$$

whence $b = \frac{\mathrm{a}^{1{,}13}}{1{,}8688}$.

TABLE No. 17.

	110	94	80	74	66
$a = CI$	27,994	26,530	25,330	24,631	24,110
Breadth of water-line at 7th div. $= c = EG$..	24,400	22,920	21,717	21,020	20,503
Breadth of parabola at 7th div. $= b = EH$..	23,100	21,745	20,632	19,990	19,513
Hence, abscissa of parabola $= a - b = x = FH$	4,894	4,785	4,698	4,641	4,597

Table No. 18.

Ordinates of the upper Water-line before the foremost ⊕ Section.

Guns.	Rules to find the abscissa, x, of the generating parabola, and the ordinates c of the line constructed accordingly.	y	Parabola.		Ordinates of the water-line
			x	b	c
110	The exponent of the parabola, $v = \frac{\text{log. } 27,994 - \text{log. } 4,894}{\text{log. } 10 - \text{log. } 7} = 4,89$, whence the abscissa, $x, = \frac{y^{4,89}}{2772,7}$, and the exponent of the line constructed accordingly $v = \frac{\text{log. } 27,994 - \text{log. } 24,4}{\text{log. } 27,994 - \text{log. } 23,1} = 0,715$, whence the ordinate $c = 2,5847\, b^{0,715}$.	10	27,994	0	0,000
		$9\frac{1}{2}$	21,786	6,208	9,536
		9	16,724	11,270	14,606
		8	9,402	18,592	20,892
		7	4,894	23,100	24,400
		6	2,303	25,691	26,327
		5	0,944	27,050	27,315
		4	0,317	27,677	27,767
94	The exponent of the parabola, $v = \frac{\text{log. } 26,53 - \text{log. } 4,785}{\text{log. } 10 - \text{log. } 7} = 4,802$, whence the abscissa, $x, = \frac{y^{4,802}}{2389,3}$, and the exponent of the line constructed accordingly $v = \frac{\text{log. } 26,53 - \text{log. } 22,92}{\text{log. } 26,53 - \text{log. } 21,745} = 0,7354$, whence the ordinate $c = 2,380\, b^{0,7354}$.	1	26,530	0,000	0,000
		$9\frac{1}{2}$	20,738	5,792	8,664
		9	15,996	10,534	13,451
		8	9,086	17,444	19,491
		7	4,785	21,745	22,920
		6	2,282	24,248	24,832
		5	0,951	25,579	25,827
		4	0,326	26,204	26,290
80	The exponent of the parabola, $v = \frac{\text{log. } 25,33 - \text{log. } 4,698}{\text{log. } 10 - \text{log. } 7} = 4,724$, whence the abscissa, $x, = \frac{y^{4,724}}{2091,0}$, and the exponent of the line constructed accordingly, $v = \frac{\text{log. } 25,33 - \text{log. } 21,717}{\text{log. } 25,33 - \text{log. } 20,632} = 0,7502$, whence the ordinate $c = 2,242\, b^{0,7502}$.	10	25,330	0,000	0,000
		$9\frac{1}{2}$	19,880	5,450	8,000
		9	15,399	9,931	12,548
		8	8,828	16,502	18,367
		7	4,698	20,632	21,717
		6	2,268	23,062	23,609
		5	0,958	24,372	24,608
		4	0,334	24,996	25,080

TABLE No. 18.—(*continued.*)

Guns.	Rules to find the abscissa, x, of the generating parabola, and the ordinates c of the line constructed accordingly.	y	Parabola.		Ordinates of the water-line c
			x	b	
74	The exponent of the parabola, $v = \frac{\log. 24,631 - \log. 4,641}{\log. 10 - \log. 7} = 4,68$, whence the abscissa, $x, = \frac{y^{4,68}}{1943,0}$, and the exponent of the line constructed accordingly $v = \frac{\log. 24,631 - \log. 21,02}{\log. 24,631 - \log. 19,99} = 0.7593$, whence the ordinate $c = 2,1624\, b^{0,7593}$.	10	24,631	0,000	0,000
		$9\frac{1}{2}$	19,376	5,255	7,622
		9	15,044	9,687	12,127
		8	8,669	15,962	17,719
		7	4,641	19,990	21,020
		6	2,256	22,375	22,899
		5	0,961	23,670	23,898
		4	0,338	24,293	24,374
66	The exponent of the parabola, $v = \frac{\log. 24,11 - \log. 4,597}{\log. 10 - \log. 7} = 4,646$, whence the abscissa, $x, = \frac{y^{4,646}}{1835,8}$, and the exponent of the line constructed accordingly, $v = \frac{\log. 24,11 - \log. 20,503}{\log. 24,11 - \log. 19,513} = 0,766$, whence the ordinate $c = 2,1059\, b^{0,766}$.	10	24,110	0,000	0,000
		$9\frac{1}{2}$	18,997	5,113	7,350
		9	14,777	9,333	11,654
		8	8,549	15,561	17,240
		7	4,597	19,513	20,503
		6	2,246	21,864	22,370
		5	0,963	23,147	23,369
		4	0,341	23,769	23,848

19. *To construct the part of the load-water section, abaft the foremost ⊕ section.*

Let CD (Fig. 64) be the middle line of the ship. $CT = DB =$ the greatest half-breadth of the water-line; draw TB. Let DC be $=$ the distance from the sternpost to the foremost ⊕ section, and divide this distance into 10 equal parts; let H be the 7th division from the ⊕ section. As the water-line must not continue straight in midships too far, the half-breadth is diminished $\frac{1}{400}$ part $= Td$, and draw the line de parallel to CD.

Suppose ThF to be the form of the water-section continued to E, and that $dhFE$ is a parabola with the vertex in d; let the distance Cd or De be $= c$, $DE = b$, which are expressed for ships of 110 and 74 guns by c, c and b, b; then

$\mathrm{c}^n : c^n :: \mathrm{b} : b$, hence $n = \dfrac{\log.\ \mathrm{b} - \log.\ b}{\log.\ \mathrm{c} - \log.\ c} =$

$\dfrac{\log.\ 15{,}00 - \log.\ 11{,}833}{\log.\ 28{,}065 - \log. 24{,}693} = 1{,}853$; therefore $b = \dfrac{c^{1{,}853}}{32{,}163} =$

DE for all ships. Put the abscissa Ee, for ships of 110 and 74 guns $= \mathrm{w}$ and w, and the abscissa FG, for ships of 110 and 74 guns $= \mathrm{x}$ and x, then $\mathrm{w}^v : w^v :: \mathrm{x} : x$, hence

$$v = \frac{\log.\ \mathrm{x} - \log.\ x}{\log.\ \mathrm{w} - \log.\ w} = \frac{\log.\ 3{,}49 - \log.\ 3{,}48}{\log.\ 13{,}065 - \log.\ 12{,}86} = 0{,}1814,$$

also $x = 2{,}1896 \,.\, w^{0{,}1814}$ for the 7th section of all ships.

Table No. 19.

The foremost part of the Ordinates of the load-water section, which are abaft the foremost ⊕ section.

		110	94	80	74	66
Half-breadth $= \frac{1}{2} B$		28,135	26,26	25,46	24,755	24,23
Half-breadth diminished by $\frac{1}{400}$ part $= De = c$		28,065	26,593	25,396	24,693	24,169
$ED = \frac{c^{1,863}}{32,163} = b$		15,000	13,575	12,464	11,833	11,408
$Ec = c - b = w$		13,065	13,018	12,932	12,860	12,761
At the section 7, $GF = 2,1896 \,.\, w^{0,1814} = x$		3,490	3,488	3,484	3,480	3,475
$x = y^s$, Exp. $s = \frac{\log. w - \log. x}{\log. 10 - \log. 7}$ hence $x =$		$\frac{y^{3,701}}{384,49}$	$\frac{y^{3,692}}{377,99}$	$\frac{y^{3,677}}{367,57}$	$\frac{y^{3,665}}{359,53}$	$\frac{y^{3,647}}{347,63}$
	y	x	x	x	x	x
When the distance from the after end of the water-line to the foremost ⊕ section is divided into 10 equal parts, the following are the corresponding abscissæ.	10	13,065	13,018	12,932	12,860	12,761
	9	8,846	8,822	8,778	8,741	8,690
	8	5,721	5,711	5,693	5,677	5,655
	7	3,490	3,488	3,484	3,480	3,475
	6	1,973	1,974	1,977	1,978	1,981
	5	1,005	1,007	1,011	1,014	1,019
	4	0,440	0,442	0,445	0,448	0,451
	y	$c-x=b$	$c-x=b$	$c-x=b$	$c-x=b$	$c-x=b$
Parabola or half-breadth of the water-section from the middle-line.	10	15,000	13,575	12,464	11,833	11,408
	9	19,219	17,771	16,618	15,952	15,479
	8	22,344	20,882	19,703	19,016	18,514
	7	24,575	23,105	21,912	21,215	20,694
	6	26,092	24,619	23,419	22,715	22,188
	5	27,060	25,586	24,385	23,649	23,150
	4	27,625	26,151	24,951	24,245	23,718

Table No. 20.

To form the after part of the Load-water Section at the Quarters.

	110	94	80	74	66
Put $BI = g$, and a = the distance between the two ⊕ sections.	B			b	
$\frac{1}{2}B$..	28,135	26,66	25,46	24,755	24,23
$y = \frac{\log. g - \log. G}{\log. B - \log. b} = \frac{\log. 12{,}20 - \log. 10{,}65}{\log. 28{,}135 - \log. 24{,}755}$ $= 1{,}062$; hence $g = \frac{B^{1,062}.\ G}{b^{1,062}} = \frac{368{,}51}{b^{1,062}}$ $= g$..............................	10,66	11,28	11,84	12,20	12,48
$\frac{\frac{1}{2}L + a}{5}$ = the distance SL..........	23,46	22,23	21,05	20,36	19,89
PN is taken according to the construction $= s$..............................	7,26	6,27	5,47	4,98	4,61
$\frac{s^{0,793}}{1{,}6162}$ = OP	2,98	2,65	2,381	2,21	2,079

The construction is made agreeably to this table. Draw DI. From the point L draw LP, a tangent to the curve-line FE; take $DM = KE$, and draw LM, and from P draw NP to the middle point of the line LM. Through the point O, at the distance $\frac{1}{4}PN$, draw the tangent QR parallel to LM. Between the tangents LP, QR, and MP, draw the parabola LOM; then the form of the after end of the water-line is completed. The form of the water-line according to this construction is $dhFLOMD$; but as this is drawn by the diminution of $\frac{1}{400}$ part of the breadth, a curve-line Uh is drawn, which touches the line BT in U, and touches the parabola in h, at the 4th division; then $TUhFLOMD$ is the form of the load-water section abaft the foremost ⊕ section.

20. *To form the plan of the half-breadth line from the foremost ⊕ section to the place where the height of breadth meets the stem.*

The same manner is adopted in the formation of this line, as of the foremost part of the water-line; that is, the distance from the foremost ⊕ section to the place B (Fig. 65), where the half-breadth meets the stem, is divided into 10 equal parts; the half-breadth is diminished $\frac{1}{200}$ part $= HF$, and put $HE = a$; let HLB be the generating parabola, with its vertex in H. It has been found by experience that at the 8th division from the ⊕ section EF, the abscissa OL for ships of 110 guns must be $= 10{,}487 = x$, and the ordinate

$\mathrm{KL} = 8 = y$, also $x = \dfrac{y^{4,4}}{897,3}$.

As $a = 27{,}994$, $a - x = 17{,}507 = b$; and it has been found that the breadth MN of the half-breadth line at the 8th division should be $= 21{,}85 = c$; then the exponent of

the breadth-line $v = \dfrac{\log. 27{,}994 - \log. 21{,}85}{\log. 27{,}994 - \log. 17{,}507} = 0{,}5182$,

and hence the length of the ordinates $c = 4{,}957 \cdot b^{0,5182}$.

y	x	b	Ordinate c
10	27,994	0,000	0,000
9½	22,338	5,656	12,166
9	17,609	10,385	16,669
8	10,487	17,507	21,850
7	5,828	22,166	24,692
6	2,957	25,037	26,300
5	1,326	26,668	27,174

These ordinates determine the breadth-line no further aft than to section 5, whence it is drawn to the ⊕ section, where it coincides with the breadth of the water-line.

On forming the half-breadth Line abaft the aftermost ⊕ Section.

The distance from C to A is divided into 10 equal parts; the half-breadth from the ⊕ section to section 3, is equal to that of the water-line; but abaft this section it runs out, so that at $A\,Q$, the after end of the water-line, the half-breadth is 0,7 the half-breadth in midships. The abscissa $P\,Q = 8{,}44 = x$, and at the 4th division the abscissa $R\,S = 0{,}8 = x$; hence the exponent of the ordinate y, $v = \dfrac{\log. \mathrm{x} - \log. x}{\log. \mathrm{y} - \log. y} = \dfrac{\log. 8{,}44 - \log. 0{,}8}{\log. 10 - \log. 4}$ $= 2{,}571$, and $x = \dfrac{y^{2{,}571}}{44{,}13}$; thus $\frac{1}{2}\,B - x = b$, the ordinate of the breadth-line.

From these expressions for the values of the ordinates c and b of the fore and after parts, the ordinates of the half-breadth of all ships of the line are obtained, in proportion to their breadth in midships; that is to say, that the plan of the breadth-lines of all ships is similar, both before and abaft the ⊕ section.

y	x	Ordinate b
$\mathrm{y} = 10$	$\mathrm{x} = 8{,}44$	19,70
9	6,44	21,70
8	4,75	23,39
7	3,37	24,77
6	2,27	25,87
5	1,42	26,72
$y = 4$	$x = 0{,}80$	27,34
$\frac{1}{2}\,B$	000	28,135

Chap. VII.—*On the form of the ⊕ Section.*

It is said in § 17, that the load-water section is the most important element in the whole construction, because the stability of the ship depends principally on it; the form of the ⊕ section, however, affects also the stability of the ship. This leads to the consideration of a circumstance which must be attended to in the construction of the ⊕ sections of ships of the line.

There has generally been no other difference of form below the water, between a ship of the line and a merchant ship, than that the latter is fuller, in order to carry a great lading; or that the former is sharper in the water; that is, has a decrease in the displacement; but where this decrease should take place, in order to render a ship of the line a good sailer, remains to be considered.

The circumstances in which these ships differ so widely from each other have not been properly considered, nor the casualties which, during a voyage, befal ships fitted for such dissimilar purposes. A ship of the line, in consequence of its heavy armament, has its centre of gravity commonly a little above the water-line; but a merchant-ship has its centre of gravity nearly always below the water-line. The weights which are above the water in the former, never undergo any change, either in quantity or situation; but the weights which are below the water, namely, provisions and ammunition, undergo a continual change.

Suppose the case of a ship of the line being at sea, and having consumed, for example, three-fourths of the provisions and ammunition, it then happens, 1. That the centre of gravity of the ship and lading is removed higher up in the ship than it was at first; and 2. That the ship itself rises considerably higher out of the water, whereby the centre of gravity of the ship and lading rises higher above the water, than the ship itself rises; but the metacentre is nearly at the same place in the ship as before, by which the stability is much diminished, which in ships of the line is a great fault. In the merchant-ship the case is very different: its lading is constantly below

the water in the hold, and is never moved during the voyage. When the water and provisions for the crew, which are about one-third as much as for a ship of the line, and constitute a weight always above the water, are chiefly consumed, the centre of gravity becomes lower in the ship than before, but the ship rises out of the water a height corresponding to this reduction of weight; and as the metacentre does not lower, the distance between the metacentre and the centre of gravity becomes greater, and consequently, at the conclusion of a voyage, the ship has gained instead of having lost in stability. Thus the form of merchant-ships does not require any particular consideration,[1] but it is different with ships of the line.

22. As the centre of gravity of the ship and lading rises during a voyage in all ships of the line, they must have the best form in relation to this circumstance; which only requires, that the form may be such, that by this rising of the centre of gravity they do not lose too much stability. This will be now examined.

To see the effect of this circumstance, take two ships of the line, with their ⊕ sections of different forms, but in all other respects similar. For the sake of illustration, let these ships be represented by two prismatic models of equal length, whose transverse sections are similar to their respective ⊕ sections, the ⊕ section having the greatest influence on the qualities which enter into the present consideration. The section of one of the models is formed according to the principle commonly adopted in the design of the ⊕ section by other nations, and the section of the other model is formed according to the principle which is adopted in this work. The difference in the form of these ⊕ sections is carried to the extreme, in order that the results may be the more evidently distinguished.

Suppose that each model has upper works, and that each has two weights, the one below the water which expresses the lading in the hold of the ship, which is equal in both to two-

[1] Likewise in the merchant-ships which sail sometimes with, and sometimes without lading, or in ballast, the breadth must continue some distance below the water-line, in order that they may not lose too much in stability when they are less deeply laden, and may carry sufficient sail, to avoid danger on a lee-shore.

sevenths of the displacement, and that its centre of gravity is in the centre of gravity of the displacement; and that the other weight above the water-line is so placed, that the common centre of gravity of both these weights coincides with the centre of gravity of the model. The following demonstration gives the reasoning on it.

Suppose that the breadth AB (Fig. 66) of the section of the model or of the ⊕ section = 50 ft. = $2y$, its depth AI = 20 ft., and that EP is the middle line. Take $EC = \frac{1}{2} EI$, and $ED = \frac{1}{2} EK$, and draw CA, DB, by which the figure $ABDCA$ is formed, which will represent the usual ⊕ section among other nations, which will be called No. 1.

Take $AF = \frac{1}{2} AI$, $BG = \frac{1}{2} BK$, and draw EF, EG, by which the figure $ABGEFA$ is formed, which will represent the received form of the ⊕ section in this work, which will be called No. 2. These sections are thus equal in breadth, depth, and area, which is = 750 square feet = A.

In No. 1 the centre of gravity of the displacement below the water-line $AB = 8{,}89 = Hi$, and[1] $\frac{\frac{2}{3} y^3}{A} = \frac{10417}{750} = 13{,}89$, and when 8,89 is subtracted from this quantity, there remains 5 feet = Hm, which is the distance that the metacentre is above the water-line; and if the common centre of gravity is supposed to be in the water-line, then the moment of stability is $= 5 . 750 = 3750$.

In No. 2 the centre of gravity of the displacement is = 7,91 feet = Hb, below the water-line AB, and as $\frac{\frac{2}{3} y^3}{A}$ is equal in both, then $13{,}89 - 7{,}91 = 5{,}98$ feet = He.

Now as the centre of gravity of the ship and lading in No. 1 is in the waterline, and the lading in the hold in No. 2 is 0,98 foot higher than in No. 1, also as all the weight in the hold is two-sevenths of the whole displacement, the centre of gravity of the ship and lading rises $0{,}98 . \frac{2}{7} = 0{,}28$ foot = Ha, above the centre of gravity of the former ship, so that the distance between the metacentre and the centre of gravity of the ship

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[1] See § 5 in the "Treatise on Ship-building," printed at Stockholm in 1775.

and lading $= He - Ha = 5{,}98 - 0{,}28 = 5{,}7 = a\,e$; hence the moment of stability of No. 2 $= 5{,}7 \,.\, 750 = 4275$.

Suppose that these ships are at sea, and that an equal quantity of provisions and ammunition is consumed in each.

Let No. 1 by this diminution of lading be lightened $1\frac{1}{2}$ foot. Take $AL = BM = 1\frac{1}{2}$ foot, and draw ML; then ML is now above the water-line, hence $PN = PO = 24{,}06$, also the area of the raised part $ABONA = 73{,}59$; also the area $NODEN = 676{,}41 = B$; $\frac{\frac{2}{3}y^3}{B} = \frac{9285}{670{,}41} = 13{,}73$. The centre of gravity of the displacement below the water-line $NO = 8{,}28 = Pl$, which subtracted from $13{,}73 = 5{,}45 = Pn$, is $=$ the height of the metacentre above the latter water-line; when 1,5 is subtracted from this quantity, there remains $3{,}95 = Hn$; and as the common centre of gravity is now by calculation 0,97 foot[1] $= Hk$, higher than the former, the distance between this latter centre of gravity and the metacentre is $= 3{,}95 - 0{,}97 = 2{,}98$ feet $= kn$, which multiplied by $676{,}41 = 2015{,}6$, is $=$ the moment of stability.

No. 2 will be now examined, in which, as was mentioned, an equal quantity of provisions and ammunition is consumed as in No. 1; also $\frac{73{,}59}{50} = 1{,}47 = AQ = BR$, and QR is now above the water-line. $\frac{\frac{2}{3}y^3}{B} = \frac{10417}{676{,}4} = 15{,}4$. The centre of gravity of the displacement below the latter water-line $= 7{,}07 = pd$, which subtracted from 15,4, gives 8,33 feet $= pf$, which is the height of the metacentre above the latter water-line. Set off 1,47, then $6{,}86 = Hf$, and as the common centre of gravity is now by calculation $0{,}86 = ac$, higher than with the full lading; viz. $0{,}86 + 0{,}28 = 1{,}14 = Hc$, above the former water-line, the distance between this centre of gravity and its metacentre is $= Hf - Hc = 6{,}86 - 1{,}14 = 5{,}72 = cf$, which multiplied by 676,41 is $= 3869$. Thus the moments of stability are:

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[1] See § 21 and 22 in "Kännedom af Linie-skepp."

Of No. 1 { With the full lading ...... = 3750
With the diminished lading = 2016 }

Of No. 2 { With the full lading ...... = 4275
With the diminished lading = 3869 }

When ships according to the principles adopted in No. 1 and No. 2 have their ⊕ sections rounded off agreeably to the common form, the moments of stability are much nearer to each other than in the results here inserted; but it is likewise seen, that No. 1, with the diminished lading, loses very much in stability compared with the stability with the full lading; whereas No. 2 with the diminished lading loses but little compared with the stability with the full lading, and is stiffer than No. 1 with the full lading; and as this is occasioned by continuing the breadth below the water-line, it thus proves, that this new principle is the proper one, and should therefore be adopted in ship-building, not only for ships of the line, but also for frigates designed for war. See more on this subject in the before-mentioned treatise on ship-building, § 9.

If it should be asked, how the common expression for the moment of stability can determine the proper height of the metacentre on the middle line; continue the line *C A* to *S*, and draw the line *S T* (which is supposed to represent the inclination of the ship) at an angle of from 8 to 9 degrees with the water-line *A B*, and so that it is at such a height, that the area of the figure contained below this water-line is equal to the area below the water-line *A B*. Then find the centre of gravity of the figure below the line *S T*, and from this centre draw a line at right angles to the line *S T* produced, then it will be found, that it meets the middle line *E P* at the same place as to height as is determined by the common expression; but if the side had been straight, as *A U*, the metacentre would have been a little lower, and the ship therefore would have had less stability. Thus it appears that the new principle has not been over-rated.

Again.—If the calculations just made are examined, it will be found that the distance which the centre of gravity of the displacement is below the water-line is different in the two figures, as well with the full as with the diminished lading.

Centre of gravity of the displacement below the water-line in . .	No. 1	With the full lading.	= 8,89
		With the diminished lading	= 8,28
	No. 2	With the full lading.	= 7,91
		With the diminished lading	= 7,07

These investigations may suggest the formation of the laws of bodies lying in the water and of less specific gravity than the water.

Law 1. If a homogeneous body lies in or is thrown into the water, it does not become quiescent, till the centre of gravity of the body and the centre of gravity of the displacement become, first, in the same vertical line; and secondly, as near to each other as possible, whether the centre of gravity of the body be above or below the water's surface.

Law 2. If two bodies lying in the water have their centres of gravity similarly situated with respect to the water-line, also have equal magnitude and weight, but dissimilar forms; that body lies the steadier, and requires the greater force to incline it from its horizontal position, which has its centre of gravity of displacement nearest to the water-line. § 17.

Law 3. If an angular rolling is given to a body floating on the water, it revolves round its centre of gravity, whether this centre be above or below the water-line; and the force which causes this rolling is in proportion to the distance between the centre of gravity and the metacentre, multiplied into the weight of the body.

For the confirmation of what has been said on the form of the ⊕ section, which has great fulness at the water-line, the following account is given:

1. In the year 1766 two frigates of 24 guns were built, *Trolle* and *Sprengporten*, both with the same fulness of ⊕ section at the water's surface; they were very stiff, easy in all their motions, and excellent sailers. 2. In the year 1778, the *Vasa*, a ship of 60 guns, was built, with the same kind of ⊕ section; the displacement was 69000 cubic feet, the ballast 1080 ship-ponds provision weight, the greatest part of which was iron, the remainder slag. With a battery of 7 feet it was stiffer than any other ship in the fleet, and was also a good sailer; and at the end of a voyage, when lightened ¾ foot, the stability

was but little diminished. On the contrary, the ship *Fredrick Adolph*, of 62 guns (see the table in the introduction), had 73200 cubic feet of displacement, 1900 skipponds of the same kind of ballast, $5\frac{3}{4}$ feet height of battery, the ⊕ section of the usual form, and whose stability was about equal to that of the other ships of the fleet, and was thus less stiff than the *Vasa*. To the *Fredrick Adolph* may be compared the *Sophia Magdalena*, of 70 guns, which had 81000 cubic feet of displacement, and 2700 skipponds provision weight of ballast, also about the same height of battery as the ship just-named; with a flatter bottom. 3. Between the years 1781 and 1785, ten ships of 62 guns were built, and ten frigates of 40 guns, all with the same kind of ⊕ section as the drawings of this work show; that is, with a continued fulness near the water-line, with little ballast; but they were quite stiff enough, and excellent sailers.

By the evidence of these examples we must be convinced, that the ⊕ sections of all ships of war should have the form adopted in this work.

23. *To construct the ⊕ Section.*

In order to form a general rule for the ⊕ sections of ships of the line, the ⊕ sections of two ships, namely, one of 110 and the other of 74 guns, have been constructed: the roman letters indicate the larger ship, and the italic the smaller ship. The half-breadth A B (Fig. 67) = $\frac{1}{2}$ B for the ship of 110 guns, and $\frac{1}{2}$ *B* for the ship of 74 guns. *A C* = **k**, which is found in the table No. 15; as well as **h**, which is here h and *h* *C E* = b and *b*, *C G* = *E H* = d and *d*, *H I* = m and *m*; the radius *D L* = w and *w*. *A G* is the depth of the ⊕ sections of construction = p and *p*, and *A N* their depth to the keel = q and *q*. *N P* is the half-siding of the keel. The line *G I*, which is a tangent to the curves *B L E Q* and *Q P*, is then drawn, which completes the form of the whole ⊕ section below the water. To find the distances *b*, *d*, *m*, *w*, *p*, and *q*, the following exponential calculations are used.

To find the distance *b*, the exponent of B = *v* =

$$\frac{\log.\,\mathrm{b} - \log.\,b}{\log.\,\tfrac{1}{2}\,\mathrm{B} - \log.\,\tfrac{1}{2}\,B} = \frac{\log.\,17{,}45 - \log.\,14{,}79}{\log.\,28{,}135 - \log.\,24{,}755} = 1{,}292\,;$$

hence $b = \dfrac{\tfrac{1}{2}\,B^{1{,}292}}{4{,}2721}$. For the distance d, the exponent of $b =$

$$v = \frac{\log.\,d - \log.\,\mathrm{d}}{\log.\,\mathrm{b} - \log.\,b} = \frac{\log.\,3{,}83 - \log.\,3{,}64}{\log.\,17{,}45 - \log.\,14{,}79} = 0{,}308\,;$$

hence $d = \dfrac{\mathrm{b}^{0{,}308}.\,\mathrm{d}}{b^{0{,}308}} = \dfrac{8{,}7816}{b^{0{,}308}}$. For the distance m, the expo-

nent of $d = v = \dfrac{\log.\,m - \log.\,\mathrm{m}}{\log.\,d - \log.\,\mathrm{d}} = \dfrac{\log.\,3{,}59 - \log.\,3{,}37}{\log.\,3{,}83 - \log.\,3{,}64}$

$= 1{,}243$; hence $m = \dfrac{d^{1{,}243}}{1{,}4785}$. For the distance w, the ex-

ponent $v = \dfrac{\log.\,\mathrm{w} - \log.\,w}{\log.\,\overline{\tfrac{1}{2}\,\mathrm{B} - \mathrm{b}.\,\mathrm{h}} - \log.\,\overline{\tfrac{1}{2}\,B - b.\,h}} =$

$\dfrac{\log.\,5{,}09 - \log.\,4{,}9}{\log.\,170{,}96 - \log.\,138{,}29} = 0{,}18$; hence $w =$

$2{,}0175\,.\,\overline{\tfrac{1}{2}\,B - b\,.\,h}^{\,0{,}18}$. And for q, the depth of the ⊕ sec-

tion to the keel, the exponent of $p = v = \dfrac{\log.\,\mathrm{q} - \log.\,q}{\log.\,\mathrm{p} - \log.\,p} =$

$\dfrac{\log.\,21{,}98 - \log.\,19{,}62}{\log.\,21{,}752 - \log.\,18{,}981} = 0{,}834$; hence $q = 1{,}6849\,p^{0{,}844}$.

The results of all these expressions are given in the following table:—

TABLE No. 21.

	110	94	80	74	66	52
$\frac{1}{2}$ B =	28,135	26,660	25,460	24,755	24,230	22,500
h =	16,000	15,157	14,348	13,878	13,526	12,795
b =	17,450	16,277	15,337	14,790	14,386	13,073
d =	3,640	3,719	3,788	3,830	3,863	3,979
m =	3,370	3,461	3,541	3,590	3,629	3,764
$\frac{1}{2}$ B − b =	10,685	10,383	10,123	9,965	9,844	9,427
w =	5,090	5,015	4,943	4,900	4,866	4,780
k =	18,112	16,986	15,917	15,151	14,654	12,905
Depth of the ⊕ section of construction = **k** + d = p =	21,752	20,705	19,605	18,981	18,517	16,884
Depth of the after ⊕ section to upper edge of rabbet q =	21,980	21,095	20,156	19,620	19,219	17,795
Depth of keel and false-keel from rabbet .... =	2,17	2,08	2,00	1,92	1,83	1,82
Greater draught of water abaft, and less draught of water forward, than at the ⊕ section, at the extremities of the water-line .... =	1,00	0,96	0,92	0,90	0,88	0,91
Siding of keel at the ⊕ section .... =	1,83	1,77	1,71	1,65	1,58	1,44

When the ⊕ section is obtained by this construction, the area $B.$ **k** is determined in Table No. 15; and when the form of the ⊕ section is obtained, the form of all the other sections remains to be determined.

Chap. VIII.—*To construct the Sections before and abaft the ⊕ Section.*

24. From the point E (Fig. 68) which answers to the point E in fig. 67, draw the line $E\,I$, which is the diagonal of construction abaft, so as to make with the vertical line $E\,F$ an angle $F\,E\,I = 27^\circ\ 9'$ (§ 12); also for the sections forward, set off the point G, answering to the point E, and draw the vertical line $G\,H$, then $G\,H = E\,F = \mathbf{k}$; from C set off $C\,K =$ the half-siding of the stem, and draw $G\,K$; then the diagonal of construction for the fore part of the ship is obtained.

For all the sections, as well abaft as forward, their form is determined at three places, namely, at the height of the breadth-line, at the water-line, and at the rabbet of the keel; it then remains to determine it at the fourth place, which is on the diagonals $E\,I$ and $G\,K$. It is then the object, that the places of the sections may be such on the diagonals, that the area of each section may be equal to the area determined.

To arrive at this result, it is found necessary to determine this point on the diagonal in the first place for the 7th section (Fig. 68), as well abaft as forward, for all the ships; for which a general rule is required, founded on the ordinates of the line of sections, $Q\,V\,K\,D\,H\,F\,g\,W$, which for the 7th section abaft $= M\,F = k$, and for the 7th section forward $= O\,V = k$. The line $S\,P\,K\,D\,N\,Q$ (Fig. 61), is the true line or diagonal of construction, and it is this line which determines the points N and P on the diagonals $E\,I$ and $G\,K$ (Fig. 68). The construction of this true line, whose ordinates $M\,N$ and $O\,P = C$, will be obtained from the ordinates of the line of sections $M\,F$ and $O\,V = k$ (Fig. 60 and 61).

But to find the distance C, as well for the 7th section abaft $= M N$, as for the 7th section forward $= O P$, these distances have been taken agreeably to the drawings of ships of 110 and 74 guns, from which the following rules have been made:

$$110 \begin{cases} \text{Abaft } k \text{ is} = 9{,}012 \text{ and } M N = C = 9{,}22 \\ \text{Forward } k \text{ is} = 11{,}639 \text{ and } O P = C = 13{,}48 \end{cases}$$

$$74 \begin{cases} \text{Abaft } k \text{ is} = 7{,}258 \text{ and } M N = C = 7{,}37 \\ \text{Forward } k \text{ is} = 9{,}463 \text{ and } O P = C = 11{,}13 \end{cases}$$

$C = \frac{k^v}{s}$, the exponent abaft, $v = \frac{\log. 9{,}22 - \log. 7{,}37}{\log. 9{,}012 - \log. 7{,}258} =$ 1,035; therefore $C = \frac{k^{1{,}035}}{1{,}0556}$. $C = s\, k^v$, the exponent, $v = \frac{\log. 13{,}48 - \log. 11{,}13}{\log. 11{,}639 - \log. 9{,}463} = 0{,}9255$; therefore $C = 1{,}3905.\, k^{0{,}9255}$.

The distances k and c are as follow:

		110	94	80	74	66	52
Abaft..	$MF = k =$	9,012	8,365	7,657	7,258	6,961	5,628
	$MN = C =$	9,220	8,536	7,789	7,370	7,058	5,664
Forward	$OV = k =$	11,639	10,833	9,956	9,463	9,097	7,541
	$OP = C =$	13,480	12,614	11,665	11,130	10,731	9,021

To find the ordinates h for all the sections abaft, also the ordinates k, by which the whole line of sections is formed, and finally, to find thence the ordinates C which form the true line, and from these ordinates k, the areas of the sections.

For the line of sections $W g F H D$ (Fig. 60 and 61), the ordinates $C D = \mathbf{h}$ are found for the ⊕ sections of all the ships in Table No. 15, and then this quantity $\mathbf{h}$ is multiplied into the number, which is found in the column E (Table No. 14), and thus the ordinates h for all the after-sections are obtained; and when e, which is found in the Table No. 15, is added thereto, the ordinates k are obtained for all the sections

which form the after-line of sections, and thence the ordinates C, which form the true line $D\,N\,Q$ (Fig. 61).

For the parabola $K\,V\,Q$ (Fig. 60 and 61) which forms the line of sections before the foremost ⊕ section, whose equation $x = \frac{y^m}{s}$, the exponents m are found for all the ships in Table No. 15, which give the ordinates k, and thence the ordinates C, which form the true line $K\,P\,S$ (Fig. 61) for the fore part of the ship.

The following table will elucidate what has been said:—

Table No. 22.

To find all the Points h and k of the Sections, also the Areas of the Sections and the True Line C, for all the Ships.

For a Ship of 110 Guns; abaft.

$\frac{1}{2}B = 28,135$, $\mathbf{h} = 16$, $e = 2,112$, $g = 6,24$.

Let $C = r\,k^v$, then $v = \frac{\log. 18,112 - \log. 9,22}{\log. 18,112 - \log. 9,012} = 0,9673$, therefore $C = 1,0994\,k^{0,9673}$.

y	h	$h+e=k$	Areas of Sections $\frac{1}{2}B.k$	True line C
⊕	16,000	18,112	509,60	18,112
1	15,890	18,002	506,49	18,005
2	15,500	17,612	495,51	17,625
3	14,660	16,772	471,88	16,813
4	13,200	15,312	430,80	15,396
5	11,330	13,442	378,19	13,573
6	9,190	11,302	317,98	11,477
7	6,900	9,012	253,55	9,220
8	4,610	6,650	187,10	6,871
9	2,310	4,020	113,10	—
10	0,000	2,112	—	—

For a Ship of 110 Guns; forward.

$\mathbf{k} = 18,112$, the exponent $m = 2,885$ (Tab. 15), x, which represents the abscissas of the generating parabola KVQ, $= \frac{y^{2,885}}{42,368}$; let $C = \overline{1-v}\,k + v\sqrt{\mathbf{k}k}$; then $v = \frac{C-k}{\sqrt{\mathbf{k}k} - k} = 0,6392$, and $0,3608k + 0,6392\sqrt{\mathbf{k}k} = C$.

y	x	$\mathbf{k}-x=k$	Areas of Sections $\frac{1}{2}B.k$	True line C
10	18,112	0,000	0,00	0,000
9	13,365	4,747	133,56	7,640
8	9,514	8,598	241,91	11,079
7	6,473	11,639	327,46	13,480
6	4,149	13,963	392,85	15,204
5	2,452	15,660	440,59	16,416
4	1,288	16,824	473,34	17,229
3	0,562	17,550	493,77	17,729
2	0,174	17,938	504,69	17,994
1	0,024	18,088	508,91	18,096
⊕	0,000	18,112	509,60	18,112

TABLE No. 22.—(*continued.*)

For a Ship of 94 Guns; abaft.

$\frac{1}{2}B = 26{,}66$, $\mathbf{h} = 15{,}157$, $e = 1{,}829$, $g = 5{,}4$.

The exponent $v = \dfrac{\log. 16{,}986 - \log. 8{,}536}{\log. 16{,}986 - \log. 8{,}365} = 0{,}9714$; therefore $C = 1{,}0844\, k^{0{,}9714}$.

y	h	$h + e = k$	Areas of Sections $\frac{1}{2}B \cdot k$	C
⊕	15,157	16,986	452,85	16,986
1	15,053	16,882	450,08	16,885
2	14,693	16,522	440,48	16,535
3	13,888	15,717	419,02	15,752
4	12,505	14,334	382,15	14,404
5	10,733	12,562	334,90	12,671
6	8,706	10,535	280,87	10,680
7	6,536	8,365	223,01	8,536
8	4,367	6,196	165,19	6,377
9	2,188	3,730	99,44	—
10	0,000	1,829	0,00	—

For a Ship of 94 Guns; forward.

$\mathbf{k} = 16{,}986$, $m = 2{,}8462$, $x = \dfrac{y^{2{,}8462}}{41{,}325}$ $v = \dfrac{C - k}{\sqrt{\mathbf{k}k} - k} = 0{,}6519$; therefore $0{,}3481\,k + 0{,}6519\sqrt{\mathbf{k}k} = C$.

y	x	$\mathbf{k} - x = k$	Areas of Sections $\frac{1}{2}B \cdot k$	C
10	16,986	0,000	0,000	0,000
9	12,582	4,404	117,41	7,171
8	8,998	7,988	212,96	10,342
7	6,153	10,833	288,81	12,614
6	3,968	13,018	347,06	14,225
5	2,362	14,624	389,88	15,366
4	1,251	15,735	419,50	16,135
3	0,552	16,434	438,13	16,613
2	0,174	16,812	448,21	16,868
1	0,024	16,962	452,21	16,970
⊕	0,000	16,986	452,85	16,986

TABLE No. 22.—(*continued.*)

For a Ship of 80 Guns; abaft.

$\frac{1}{2} B = 25{,}46$, $\mathbf{h} = 14{,}348$, $e = 1{,}469$, $g = 4{,}77$.

The exponent $v = \dfrac{\log. 15{,}817 - \log. 7{,}789}{\log. 15{,}817 - \log. 7{,}657} = 0{,}9764$; therefore $C = 1{,}0673\, k^{0{,}9764}$.

y	h	$h+e=k$	Areas of Sections $\frac{1}{2} B \,.\, k$	C
⊕	14,348	15,817	402,70	15,817
1	14,250	15,719	400,21	15,722
2	13,900	15,369	391,30	15,379
3	13,146	14,615	372,10	14,642
4	11,637	13,306	338,77	13,360
5	10,160	11,629	296,08	11,713
6	8,241	9,710	247,22	9,822
7	6,188	7,657	194,95	7,789
8	4,134	5,603	142,65	5,742
9	2,071	3,300	84,02	—
10	0,000	1,469	0,00	—

For a Ship of 80 Guns; forward.

$\mathbf{k} = 15{,}817$, $m\ 2{,}7832$, $x = \dfrac{y^{2{,}7832}}{38{,}377}$

$v = \dfrac{C - k}{\sqrt{\mathbf{k}\, k} - k} = 0{,}6591$; therefore $C = 0{,}3409\, h + 0{,}6591 \sqrt{\mathbf{k}\, k}$.

y	x	$\mathbf{k}-x=k$	Areas of Sections $\frac{1}{2} B \,.\, k$	C
10	15,817	0,000	0,00	0,000
9	11,797	4,020	102,35	6,626
8	8,500	7,317	186,29	9,586
7	5,861	9,956	253,48	11,665
6	3,817	12,000	305,52	13,171
5	2,298	13,519	344,19	14,247
4	1,235	14,582	371,26	14,918
3	0,554	15,263	388,60	15,444
2	0,179	15,638	398,14	15,697
1	0,026	15,791	402,04	—
⊕	0,000	15,817	402,70	15,817

TABLE No. 22.—(*continued.*)

For a Ship of 74 Guns; abaft.

$\frac{1}{2} B = 24{,}755$, $\mathbf{h} = 13{,}878$, $e = 1{,}273$, $g = 4{,}31$.

The exponent $v = \dfrac{\log.\ 15{,}151 - \log.\ 7{,}37}{\log.\ 15{,}151 - \log.\ 7{,}258}$

$= 0{,}9792$; therefore $C = 1{,}0582\, k^{0{,}9792}$

y	h	$h+e=k$	Areas of Sections $\frac{1}{2} B . k$	C
⊕	13,878	15,151	375,06	15,151
1	13,783	15,056	372,71	15,059
2	13,444	14,717	364,32	14,727
3	12,716	13,989	346,30	14,010
4	11,449	12,722	314,93	12,786
5	6,827	11,100	274,78	11,172
6	7,971	9,244	228,84	9,340
7	5,985	7,258	179,67	7,370
8	3,999	5,272	130,51	5,389
9	2,004	3,070	76,00	—
10	0,000	1,273	0,00	—

For a Ship of 74 Guns; forward.

$\mathbf{k} = 15{,}151$, $m = 2{,}7468$, $x = \dfrac{y^{2{,}7468}}{36{,}813}$

$v = \dfrac{C - k}{\sqrt{\mathbf{k}\, k} - k} = 0{,}664$; therefore

$C = 0{,}336 k + 0{,}664 \sqrt{\mathbf{k}\, k}$.

y	x	$\mathbf{k} - x = k$	Areas of Sections $\frac{1}{2} B . k$	C
10	15,151	0,000	0,00	0,000
9	11,344	3,807	94,24	6,322
8	8,208	6,943	171,87	9,143
7	5,688	9,463	234,25	11,130
6	3,724	11,427	282,88	12,576
5	2,257	12,894	319,19	13,613
4	1,223	13,928	344,79	14,325
3	0,555	14,596	361,33	14,778
2	0,182	14,969	370,56	15,029
1	0,027	15,124	374,39	—
⊕	0,000	15,151	375,06	15,151

Table No. 22.—(*continued.*)

For a Ship of 66 Guns; abaft.

$\frac{1}{2} B = 24{,}23$, $\mathbf{h} = 13{,}526$, $e = 1{,}128$, $g = 4{,}04$.

$$\text{The exponent } v = \frac{\log.\ 14{,}654 - \log.\ 7{,}058}{\log.\ 14{,}654 - \log.\ 6{,}969}$$

$= 0{,}9814$; therefore $C = 1{,}0512\, k^{0{,}9814}$.

y	h	$h+e=k$	Areas of Sections $\frac{1}{2} B.k$	C
⊕	13,526	14,654	355,07	14,654
1	13,433	14,561	352,81	14,564
2	13,103	14,231	344,82	14,241
3	12,393	13,521	327,61	13,541
4	11,159	12,287	297,71	12,327
5	9,578	10,706	259,41	10,764
6	7,769	8,897	215,57	8,980
7	5,833	6,961	168,66	7,058
8	3,897	5,025	121,76	5,126
9	1,953	2,940	71,24	—
10	0,000	1,128	0,00	—

For a Ship of 66 Guns; forward.

$\mathbf{k} = 14{,}654$, $m = 2{,}7184$, $x = \frac{y^{2{,}7184}}{35{,}682}$

$$v = \frac{C - k}{\sqrt{\mathbf{k}\, k} - k} = 0{,}6672; \text{ therefore}$$

$$C = 0{,}3328\, k + 0{,}6672 \sqrt{\mathbf{k}\, k}.$$

y	h	$h+e=k$	Areas of Sections $\frac{1}{2} B.k$	C
10	14,654	0,000	0,00	0,000
9	11,004	3,650	88,44	6,095
8	7,989	6,665	161,49	8,812
7	5,557	9,097	220,42	10,731
6	3,655	10,999	266,51	12,131
5	2,227	12,427	301,11	13,140
4	1,214	13,440	325,65	13,836
3	0,555	14,099	341,62	14,283
2	0,184	14,470	350,61	14,532
1	0,028	14,626	354,39	—
⊕	0,000	14,654	355,07	14,654

TABLE No. 22.—(*continued.*)

For a Ship of 52 Guns; abaft.

$\frac{1}{2} B = 22,5$, $\mathbf{h} = 12,795$, $e = 0,11$, $g = 2,00$.

As at the seventh section the difference between h and C is not more than 0,036, they may be taken as equal.

y	h	$h+e=k$	Areas of Sections $\frac{1}{2} B . k$	C
⊕	12,795	12,905	290,36	12,905
1	12,707	12,817	288,38	12,817
2	12,395	12,505	281,36	12,505
3	11,724	11,834	266,27	11,834
4	10,556	10,666	239,99	10,666
5	9,061	9,171	206,35	9,171
6	7,349	7,459	167,83	7,459
7	5,518	5,628	126,63	5,628
8	3,687	3,797	85,43	3,797
9	1,847	1,957	44,03	1,957
10	0,000	0,000	0,00	0,000

For a Ship of 52 Guns; forward.

$\mathbf{k} = 12,905$, $m = 2,4614$, $x = \frac{y^{2,4614}}{22,421}$

$$v = \frac{C - k}{\sqrt{\mathbf{k}\,k} - k} = 0,6665 \text{; therefore}$$

$$C = 0,3335 . k + 0,6665 \sqrt{\mathbf{k}\,k}.$$

y	h	$h+e=k$	Areas of Sections $\frac{1}{2} B . k$	C
10	12,905	0,000	0,00	0,000
9	9,957	2,948	66,33	5,094
8	7,451	5,454	122,72	7,410
7	5,364	7,541	169,67	9,090
6	3,670	9,235	207,79	10,356
5	2,343	10,562	237,64	11,304
4	1,353	11,552	259,90	11,990
3	0,666	12,239	275,38	12,458
2	0,246	12,659	284,83	12,740
1	0,045	12,860	289,35	12,875
⊕	0,000	12,905	290,36	12,905

The drawings which are constructed according to these calculations are found in plates II, III, IV, V, VI, VII. Each ship has three plates with the same number. All the sheer-draughts are marked *A*, the body-plans *B*, and the stern-views *C*.

25. Thus all the values of *C* are obtained; these values are set off perpendicularly below the water-line *A B* (Fig. 68). Those which belong to the after-part must be set off on the diagonal *E I*, and those which belong to the fore-part on the diagonal *G K*. Four points are thus obtained, through which the section should be drawn, namely, the first at the height of breadth, the second at the water-line, the third at the diagonal *E I* and *G K*, and the fourth at the keel.

When the sections are thus drawn, so that their areas may agree respectively with those before-mentioned, other diagonals are drawn on the body-plan, but so placed that they are nearly at right angles with the curve of the section, at the place where it is considered that the direction of the line of relaxation will meet the diagonal in the horizontal plan, and as far aft as is necessary; agreeably to which all the diagonals are drawn in the plan.

It is not only necessary that the sections should be drawn in this manner, and especially that their areas should also agree accurately with those before determined; a certain skill in the operation is also requisite which cannot be described,[1] but which is obtained by practice and great attention: a highly important circumstance in obtaining a knowledge of a science, in which methods may be found to lighten the work.

From these sections all the measurements are taken for finding, 1. The displacement, and the situation of the centre of gravity as to length, which will be found to agree very nearly with that inserted in Table No. 15; 2. The height of the centre of gravity of the displacement; and 3. The metacentre. The methods by which these calculations should be made are found in § 4, 5, and 6, in the "Treatise on Ship-building," printed at Stockholm, in 1775. The results of these calculations are inserted in the following table :—

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[1] The officer of construction who assisted me in the calculations, and who made all the drawings from them, can, when he is present, give satisfactory information on this subject.

TABLE No. 23.

	110	94	80	74	66	52
Displacement by measurement .... $= D =$	152900	128320	107386	96390	88681	66673
Centre of gravity before the middle of the water-line L.... =	3,795	3,550	3,470	3,407	3,349	3,717
Half area of water-section...................... $= W =$	5126,78	4574,92	4113,75	3859,98	3666,40	3164,02
$\frac{\int \frac{2}{3} y^3 \, dx}{D}$ .... $= p =$	15,204	14,445	14,107	13,916	13,721	13,430
Centre of gravity of displacement below the water-line.... =	8,552	8,079	7,578	7,279	7,081	6,323
Metacentre above water-line .... =	6,652	6,366	6,529	6,637	6,640	7,107
Depth at the extremities of the water-line, L, to the under-side of the keel: abaft	25,15	24,135	23,08	22,54	21,93	20,53
Depth at the extremities of the water-line, L, to the under-side of the keel: forward ..	23,15	22,215	21,24	20,74	20,17	18,71

As the sections of these draughts are not equally distant from each other, the space between the after-sections being greater than that between the foremost sections, they are called the construction-sections, and other sections must be drawn for the execution of the building. The reason that the other sections are not drawn is this: As the distances between the sections and the distances between the ports must agree with each other, every alternate section throughout the whole length of the ship, extending uninterruptedly from the keel to the gunwale, must run up between all the ports, and the other sections, or filling timbers, must stop under the ports; (but as some will have more and some less opening between the timbers, and it may happen that others may wish that these timbers which come between the before-mentioned sections may not be in pairs, but equally separated from each other, by which the distances between the sections are greater, and consequently also the distances between the ports;) it thus appears, that if the sections are so divided it must be in the same space; and this division not agreeing with that, which another thought better, it would have been a useless work and have caused confusion; but as a sufficient number of diagonals is found in the horizontal plan, the sections, according to whatever division may be best, may have their true areas and intended form, and the ports be arranged accordingly. Nevertheless the ports have been drawn, and some of the stations of the sections, in relation to the stations of the ports, marked in midships on the keel; and as the joints of the frames must meet at some place in the ship's length, and a single timber is added where they meet, so that the two joints may not meet at the same place, it has been thought most proper that this should be at the gang-way, by which the distance between the ports at this place is greater by the siding of one timber and an opening. This is well understood by a practical builder.

Chap. IX.—*On a Ship's Upper Works.*

27. Respecting the parts of a ship above the water, the height determines itself, but the form or tumbling home of the

topside is determined by the service to which the ship is to be applied. In a merchant ship, the straightness of side may be continued as far as may be desired, because it has little or no effect on the ship's stability; but it is otherwise with a ship of the line, when the sails are close-hauled, in a brisk topsail breeze, with the sails mentioned in the introduction, and the ship is to lee-ward of an enemy, when also all lee-ward guns should be used, and the service of the guns and small arms requires together more than two-thirds of the crew, especially in the largest ships or three-deckers, which, during the whole of the action, must be to lee-ward; it then follows, that the broader the ship is above, the further out from the middle line of the ship the men are stationed, whose weight gives the ship an inclination, which increases the heeling it has already received from the force of the wind on the sails, and when it exceeds a certain degree, the guns cannot be worked without difficulty, and it may happen that the lower-deck guns cannot be used; but the narrower the ship is above, the less is the inclination caused by the crew to lee-ward. The following consideration also limits the tumbling home, namely: as it is the guns which govern the whole affair, so there must not be any-thing in the way which may hinder their full effect; and as the upper-deck guns are those which are most subject to this hinderance, in consequence of the narrow space between the boat and the ship's side, the tumbling home of the topside is determined in this manner: that the length of the guns must be added to the distance, which is required between the inside of the ship's side and the muzzles of the guns at about half the height of the ports, so that they may be conveniently loaded, to which must be added a moderate distance between the after truck of the gun and the boat, that the men may pass between them without interruption in action. It is in this manner that the length of the guns and the breadth of the boat, with the addition here mentioned, will determine the tumbling home of the topside; and it is with reference to all these considerations that the topsides of all ships have been given the tumbling home, which is found in the plates.

28. It is in this manner that the height of the breadth-line on the drawing is found, at which the tumbling home of the

topside commences, with the sweeps of circles, whose centres are at this height of the breadth-line; and in order that the side may present a handsome appearance, the contrary flexure of the topside must continue with a fair curve along the whole side, parallel to the sheer of the ship; and this is the ticked line, which is shown just above the lower-deck ports, which must be called the top-timber line of contrary flexure. The radii of these sweeps therefore cannot be equal, because these sweeps must necessarily touch the contrary sweep of the top-timbers in this line. The remaining part of the topside which gives the usual form above the water, may be obtained from the same draughts.

The full line, which is drawn on the sheer-draught below the lower deck, shows the lower edge of the main wale; but as the upper edge is not shown there, reference may be made to Fig. 69, from which it may be taken; the wale, after continuing from the lower edge upwards some distance, is diminished in thickness, so that the wale or planking under the next or second wale is an inch thinner than the main wale. The reason that the lower wale is determined in this manner is, that the side of the ship is thereby thicker, so that the shot, which come with diminished force, or are fired from a greater distance, may not pass through the side, as they do where the side is thinner, which is so much the more important, as the greatest armament and greatest number of people are on the lower deck.

Chap. X.—*To find the Resistance a Ship experiences in moving through the Water.*

29. What is said in the introduction must be attended to: that all ships in a line of battle must sail equally well, with an equal inclination, and with the same sails set; thus it is in relation to the area of the sails, that the resistance which a ship experiences in its course must be known, as well as the stability under sail. In what manner these two circumstances together should be treated, and of what consequence they

are, is seen from what follows; but in the first place,—on the resistance.

In the new "Transactions of the Royal Academy of Sciences," for the second quarter of the year 1795, are inserted "*Experiments on the Resistance Bodies experience which move directly through the Water.*" In § 15 the expression for the resistance is found, and in § 16 the manner of obtaining the value of this expression by a geometrical construction, is seen by Fig. 18. And as by this figure the relative resistance of all bodies or vessels may be found, whether they are drawn on a larger or smaller scale, it follows, that the absolute resistance must always be the same: thus the measurements of this figure should always be by the same scale by which the figure is drawn. The scale here used is that of one-fourth of an inch to a foot.[1]

30. *To find the Effect of the Water in opposing the Course of a Ship of* 74 *Guns.*

As this effect cannot be found in any other manner than by supposing the surface of the ship composed of numerous plane triangles, the angle of incidence, and thence the relative resistance, must be found for each plane separately.

On Fig. 70, which is the body plan of a ship of 74 guns, set off from AB the upper water-line, eight distances of 2,37 feet each, which is the distance between the water-lines: draw the lines 2, 3, 4, &c.; then there are nine water-lines. Thus the spaces between the profiles of the sections, and between the water-lines on the whole body plan, are divided into rhomboids or trapeziums $CDEF$; draw the diagonal CE. Thus the body plan, and consequently the surface of the ship, is divided into a great number of plane triangles.

The method of obtaining from this body plan the direct resistance of the water on the fore-part of the ship, and the force of cohesion abaft in opposing its course, is found in the Treatise just mentioned, § 24, but with this difference: that

[1] The scale of the figures of this translation is half that of the original.

there, an equal distance is supposed to be between the sections, whereas here, the distance between the sections forward is less than the distance between the sections abaft. The shorter distances at the extremities of the ship to the stem and sternpost are taken from the drawing of the ship.

In case the reader has not the "Transactions of the Royal Academy of Sciences" mentioned in the preceding section, or the figure 18, Fig. 71 is a copy of that part of it which is necessary in finding the resistance a ship experiences in its motion through the water.

In the space $PDilXBP$, the direct resistance from the $\oplus$ section to the stem will be found, and in the space $BPpn P'rB$, the force of cohesion from the $\oplus$ section to the sternpost. On the line AB, set off from A, a distance $At =$ the distance to the section which is before the $\oplus$ section, and draw tw perpendicular to AB. From A set off $Att =$ the distance to the section which is abaft the $\oplus$ section, and draw ttu perpendicular to AB.

Suppose that the distance between the lines CB and KA (Fig. 72), and the distance between the lines LF and GE (Fig. 73), is $=$ the distance between the water-lines on the body plan (Fig. 70); that CK and BA (Fig. 72) are a part of the exterior surface between two successive sections in the fore body, also FE and LG (Fig. 73) a part of the exterior surface between two successive sections in the after body of the ship. From A (Fig. 72) draw the line AD at right angles to the line CK, and GH (Fig. 73) at right angles to the line FE. From t (Fig. 71) set off $tw = AD$, and $ttu = GH$ From A through the points w and u, draw the lines Ax and Ar; then yx is the direct resistance on that part of the fore body of the ship, and pr the force of cohesion on that part of the after body. These distances yx and pr are measured by the constant scale of feet before-mentioned. If the distance GH (Fig. 73) $= utt$, is so great that it makes an angle greater than the angle BAP', which happens abaft at the water-line, and where the sections are nearer to each other and to the sternpost, then the force of cohesion is nevertheless not greater than nP'; that is, if the ship has a flat stern, which comes down low in the water, then the force of cohesion is

nevertheless always equal to *n* P′, but never greater. The constant scale before mentioned, by which the distances *y x* and *p r* are measured (without regard to the scale, according to which the drawing of the ship is made, for whether *A t* is longer or shorter, *t w* is also in the same proportion longer or shorter, and thus the angle *B A x* is constant), is made of brass, similar to Fig. 74 and 75; but the undetermined end, M N, will be an inch longer than the distance from *P* to *A* (Fig. 71). The edges which are graduated are made thin, and both sides of the scale must either be gilt or lackered, that it may not soil the paper.

It will be seen by the following example, how the resistance of a ship of 74 guns is to be found :—

Table No. 24.

Direct Resistance before the ⊕ Section.

Between the 1st and 2nd Water-line.							
Triangle No.	Base of Triangle.	Direct Resistance	Force multiplied by the Base.	Triangle No.	Base of Triangle.	Direct Resistance	Force multiplied by the Base.
23	3,26	22,27	72,60	22	1,15	23,00	26,45
21	3,04	21,00	63,84	20	2,88	21,00	60,48
19	2,50	19,53	48,82	18	2,28	19,20	43,78
17	3,94	17,55	69,15	16	4,04	17,55	70,90
15	5,00	14,42	72,10	14	5,66	14,42	81,62
13	2,98	11,68	34,81	12	3,56	11,92	42,43
11	1,74	9,70	17,18	10	2,13	10,00	21,30
9	0,90	8,75	7,88	8	1,23	9,00	11,07
7	0,45	8,45	3,80	6	0,63	8,54	5,38
5	0,24	8,37	2,01	4	0,38	8,43	3,20
3	0,10	8,33	0,83	2	0,14	8,35	1,17
1	—	—	—	0	—	—	—
			393,02				367,78
⅓ dist. between w. lines			1,185				1,185
Sum of the effects.. =			465,60				435,82

Total effect........ = 465,60 + 435,82 = 901,42

Between the 2nd and 3rd Water-line.							
Triangle No.	Base of Triangle.	Direct Resistance	Force multiplied by the Base.	Triangle No.	Base of Triangle.	Direct Resistance	Force multiplied by the Base.
23	1,15	22,00	25,30	22			
21	2,88	21,00	60,48	20	2,00	22,00	44,00
19	2,28	19,00	43,32	18	2,06	18,80	38,73
17	4,04	17,23	69,61	16	3,77	17,15	64,66
15	5,66	14,55	82,35	14	6,06	14,55	88,17
13	3,56	12,16	43,29	12	4,13	12,16	50,22
11	2,13	10,17	21,66	10	2,55	10,35	26,39
9	1,23	9,10	11,19	8	1,64	9,37	15,37
7	0,63	8,55	5,39	6	0,90	8,70	7,83
5	0,38	8,43	3,20	4	0,57	8,48	4,83
3	0,14	8,35	1,17	2	0,23	8,37	1,93
1	—	—	—	0	—	—	—
			366,96				342,13
⅓ dist. between w. lines			1,185				1,185
Sum of the effects .. =			434,85				405,43

Total effect .... = 434,85 + 405,43 = 840,2

TABLE No. 24.—(*continued.*)

Direct Resistance before the ⊕ Section.

Between the 3rd and 4th Water-line.

Triangle No.	Base of Triangle.	Direct Resistance	Force multiplied by the Base.	Triangle No.	Base of Triangle.	Direct Resistance	Force multiplied by the Base.
23	—	—	—	22	—	—	—
21	2,00	20,47	40,94	20	0,36	20,20	7,27
19	2,06	18,53	38,17	18	1,80	18,53	33,35
17	3,77	16,75	63,15	16	3,20	16,46	52,67
15	6,05	14,40	87,26	14	5,87	14,40	84,52
13	4,13	12,24	50,55	12	4,52	12,24	55,32
11	2,55	10,56	26,93	10	3,20	10,74	34,36
9	1,64	9,48	15,55	8	2,08	9,65	20,07
7	0,90	8,76	7,88	6	1,27	8,90	11,30
5	0,57	8,48	4,83	4	0,77	8,58	6,61
3	0,23	8,37	1,93	2	0,36	8,40	3,02
1	—	—	—	0	0,12	8,32	1,00
			337,19				309,49
½ dist. between w. lines			1,185				1,185
Sum of the effects.. =			399,57				366,75

Total effect........ = 399,57 + 366,75 = 766,32

Between the 4th and 5th Water-line.

Triangle No.	Base of Triangle	Direct Resistance	Force multiplied by the Base.	Triangle No.	Base of Triangle.	Direct Resistance	Force multiplied by the Base.
23	—	—	—	22	—	—	—
21	—	—	—	20	—	—	—
19	1,80	18,15	32,67	18	0,77	18,20	12,74
17	3,20	16,10	51,52	16	2,60	15,70	40,82
15	5,87	13,70	80,42	14	4,97	13,87	68,93
13	4,52	12,00	54,24	12	4,55	12,00	54,60
11	3,20	10,75	34,40	10	3,62	10,75	38,92
9	2,08	9,75	20,28	8	2,56	9,80	25,09
7	1,27	9,03	11,47	6	1,73	9,13	15,79
5	0,77	8,70	6,70	4	0,96	8,67	8,32
3	0.36	8,40	3,02	2	0,55	8,44	4,64
1	0,12	8,32	1,00	0	0,18	8,33	1,50
			295,72				271,35
½ dist. between w. lines			1,185				1,185
Sum of the effects .. =			350,43				321,55

Total effect .... = 350,43 + 321,55 = 671,98

TABLE No. 24.—(*continued.*)

Direct Resistance before the ⊕ Section.

Between the 5th and 6th Water-line.								Between the 6th and 7th Water-line.							
Triangle No.	Base of Triangle.	Direct Resistance	Force multiplied by the Base.	Triangle No.	Base of Triangle.	Direct Resistance	Force multiplied by the Base.	Triangle No.	Base of Triangle.	Direct Resistance	Force multiplied by the Base.	Triangle No.	Base of Triangle.	Direct Resistance	Force multiplied by the Base.
23	—	—	—	22	—	—	—	23	—	—	—	22	—	—	—
21	—	—	—	20	—	—	—	21	—	—	—	20	—	—	—
19	0,77	17,10	13,17	18	—	—	—	19	—	—	—	18	—	—	—
17	2,60	15,04	39,10	16	1,90	14,07	26,73	17	1,90	13,87	26,35	16	0,83	12,50	10,37
15	4,97	12,87	63,96	14	3,80	12,73	48,37	15	3,80	11,54	43,85	14	2,52	10,92	27,52
13	4,55	11,47	52,19	12	3,85	11,40	43,89	13	3,85	10,52	40,50	12	2,63	10,15	26,59
11	3,62	10,50	38,01	10	3,60	10,37	37,33	11	3,60	9,90	35,64	10	2,80	9,54	26,71
9	2,56	9,75	24,96	8	3,00	9,65	28,95	9	3,00	9,40	28,20	8	2,63	9,10	23,93
7	1,73	9,20	15,92	6	2,10	9,10	19,11	7	2,10	9,00	18,90	6	2,24	8,80	19,71
5	0,96	8,67	8,32	4	1,28	8,67	11,10	5	1,28	8,64	11,06	4	1,55	8,57	13,28
3	0,55	8,44	4,64	2	0,70	8,44	5,91	3	0,70	8,44	5,91	2	1,85	8,41	15,56
1	0,18	8,34	1,50	0	0,27	8,36	2,26	1	0,27	8,34	2,25	0	0,35	8,34	2,92
			261,77				223,65				212,66				166,59
½ dist. between w. lines			1,185				1,185	½ dist. between w. lines			1,185				1,185
Sum of the effects..		=	310,19				265,02	Sum of the effects..		=	252,00				197,42
Total effect........		=	310,19 + 265,02 = 575,21					Total effect........		=	252,00 + 197,42 = 449,42				

Table No. 24.—(*continued.*)

Direct Resistance before the ⊕ Section.

Between the 7th and 8th Water-line.

Triangle No.	Base of Triangle.	Direct Resistance	Force multiplied by the Base.	Triangle No.	Base of Triangle.	Direct Resistance	Force multiplied by the Base.
23	—	—	—	22	—	—	—
21	—	—	—	20	—	—	—
19	—	—	—	18	—	—	—
17	0,83	11,90	9,88	16	0,18	11,40	2,05
15	2,52	10,13	25,53	14	1,30	9,15	11,90
13	2,63	9,53	25,06	12	1,34	8,95	11,99
11	2,80	9,10	25,48	10	1,32	8,71	11,50
9	2,63	8,87	23,33	8	1,42	8,58	12,18
7	2.24	8,72	19,53	6	1,50	8,52	12,78
5	1,55	8,52	13,21	4	1,10	8,41	9,25
3	1,85	8,41	15,56	2	0,80	8,36	6,69
1	0,35	8,34	2,92	0	0,40	8,33	3,33
			160,50				81,67
½ dist. between w. lines			1,185				1,185
Sum of the effects.. =			190,19				96,78

Total effect........ = 190,19 + 96,78 = 286,97

Below the 8th Water-line.

Triangle No.	Base of Triangle.	Direct Resistance	Force multiplied by the Base.
23	—	—	—
21	—	—	—
19	—	—	—
17	—	—	—
15	1,30	8,95	11,64
13	1,34	8,70	11,66
11	1,32	8,56	11,30
9	1,42	8,50	12,07
7	1,50	8,45	12,67
5	1,10	8,40	9,24
3	0,80	8,35	6,68
1	0,40	8,32	3,33
			78,59
½ dist. between w. lines			1,185
Total effect .. .. .. =			93,13

RECAPITULATION.

Between 1st and 2nd	=	901,42
2nd and 3rd	=	840,28
3rd and 4th	=	766,32
4th and 5th	=	671,98
5th and 6th	=	575,21
6th and 7th	=	449,42
7th and 8th	=	286,97
Below the 8th	=	93,13
Stem	=	188,14
Resistance before the ⊕ section ..	=	4772,87

TABLE No 24.—(*continued.*)

Force of Cohesion abaft the ⊕ Section.

Between the 1st and 2nd Water-line.

Triangle No.	Base of Triangle.	Force of Cohesion.	Force multiplied by the Base.	Triangle No.	Base of Triangle.	Force of Cohesion.	Force multiplied by the Base.
23	2,64	8,32	21,96	24	—	—	—
21	5,82	8,32	48,42	22	1,20	8,32	9,98
19	5,12	8,32	42,60	20	2,56	8,32	21,30
17	4,15	0,50	2,08	18	5,20	8,32	43,26
15	2,25	0,14	0,32	16	5,67	0,50	2,84
13	1,60	0,55	0,88	14	3,60	0,10	0,36
11	1,05	1,80	1,89	12	2,37	0,18	0,43
9	0,67	3,54	2,37	10	1,50	1,03	1,55
7	0,47	4,50	2,12	8	0,93	2,37	2,20
5	0,25	6,00	1,50	6	0,57	3,94	2,25
3	0,10	7,60	0,76	4	0,34	5,37	1,83
1	—	—	—	2	0,13	7,40	0,96
			124,90				86,96
½ dist. between w. lines			1,185				1,185
Sum of the effects.. =			148,01				103,05

Total effect........ = 148,01 + 103,05 = 251,06

Between the 2nd and 3rd Water-line.

Triangle No.	Base of Triangle.	Force of Cohesion.	Force multiplied by the Base.	Triangle No.	Base of Triangle.	Force of Cohesion.	Force multiplied by the Base.
23	1,20	8,32	9,98	24	—	—	—
21	2,56	8,32	21,30	22	0,65	8,32	5,41
19	5,20	8,32	43,26	20	1,34	8,32	11,15
17	5,67	0,80	4,54	18	2,62	8,32	21,80
15	3,60	0,14	0,50	16	5,64	0,80	4,51
13	2,37	0,11	0,26	14	4,78	0,16	0,76
11	1,50	0,80	1,20	12	3,67	1,10	0,37
9	0,93	2,23	2,07	10	2,35	0,30	0,71
7	0,57	3,94	2,25	8	1,40	1,34	1,88
5	0,34	5,37	1,83	6	0,82	2,90	2,38
3	0,13	7,00	0,91	4	0,43	4,93	2,12
1	—	—	—	2	0,20	6,90	1,38
			88,10				52,47
½ dist. between w. lines			1,185				1,185
Sum of the effects.. =			104,40				62,18

Total effect........ = 104,40 + 62,18 = 166,58

Table No. 24.—(*continued.*)

Force of Cohesion abaft the ⊕ Section.

Between the 3rd and 4th Water-line.								Between the 4th and 5th Water-line.							
Triangle No.	Base of Triangle.	Force of Cohesion.	Force multiplied by the Base.	Triangle No.	Base of Triangle	Force of Cohesion.	Force multiplied by the Base.	Triangle No.	Base of Triangle.	Force of Cohesion.	Force multiplied by the Base.	Triangle No.	Base of Triangle.	Force of Cohesion.	Force multiplied by the Base.
23	0,65	7,90	5,14	24	0,10	7,40	0,74	23	0,40	3,30	1,32	22	0,22	1,00	0,22
21	1,34	7,30	9,78	22	0,40	3,30	1,32	21	0,90	2,10	1,89	20	0,66	0,20	0,13
19	2,62	4,86	12,73	20	0,90	2,10	1,89	19	1,52	0,85	1,29	18	1,00	0,10	0,10
17	5,64	1,06	5,98	18	1,52	1,47	2,23	17	3,40	0,30	1,02	16	2,20	0,10	0,22
15	4,78	0,20	0,96	16	3,40	1,00	3,40	15	4,54	0,20	0,91	14	2,80	0,16	0,45
13	3,67	0,13	0,48	14	4,54	0,20	0,91	13	4,62	0,13	0,60	12	4,10	0,13	0,53
11	2,35	0,11	0,26	12	4,62	0,13	0,60	11	3,70	0,12	0,44	10	4,55	0,11	0,50
9	1,40	1,03	1,44	10	3,70	0,10	0,37	9	2,20	0,30	0,66	8	3,52	0,16	0,56
7	0,82	2,87	2,35	8	2,20	0,50	1,10	7	1,26	1,53	1,93	6	2,00	1,04	2,08
5	0,43	4,93	2,12	6	1,26	1,83	2,31	5	0,58	4,25	2,47	4	0,90	3,28	2,95
3	0,20	6,90	1,38	4	0,58	4,25	2,47	3	0,27	6,00	1,62	2	0,40	5,40	2,16
1	—	—	—	2	0,27	6,00	1,62	1	0,10	7,40	0,74	0	0,10	7,40	0,74
			42,62				18,96				14,89				10,64
½ dist. between w. lines			1,185				1,185	½ dist. between w. lines			1,185				1,185
Sum of the effects. .. =			50,50				22,47	Sum of the effects... =			17,64				12,61
Total effect......... = 50,50 + 22,47 = 72,97								Total effect........ = 17,64 + 12,61 = 30,25							

TABLE No. 24.—(*continued.*)

Force of Cohesion abaft the ⊕ Section.

Between the 5th and 6th Water-line.								Between the 6th and 7th Water-line.							
Triangle No.	Base of Triangle.	Force of Cohesion.	Force multiplied by the Base.	Triangle No.	Base of Triangle.	Force of Cohesion.	Force multiplied by the Base.	Triangle No.	Base of Triangle.	Force of Cohesion.	Force multiplied by the Base.	Triangle No.	Base of Triangle.	Force of Cohesion.	Force multiplied by the Base.
23	0,22	1,00	0,22	22	—	—	—	23	—	—	—	22	—	—	—
21	0,66	0,20	0,13	20	0,50	0,16	0,08	21	0,50	0,16	0,08	20	0,33	1,00	0,33
19	1,00	0,10	0,10	18	0,72	0,67	0,48	19	0,72	0,82	0,59	18	0,50	1,82	0,91
17	2,20	0,12	0,26	16	1,57	0,55	0,86	17	1,57	0,73	1,15	16	1,07	1,80	1,93
15	2,80	0,10	0,28	14	1,90	0,28	0,53	15	1,90	0,50	0,95	14	1,30	1,25	1,63
13	4,10	0,11	0,45	12	1,50	0,11	0,17	13	1,50	0,31	0,47	12	1,60	0,95	1,52
11	4,55	0,10	0,45	10	3,56	0,10	0,36	11	3,56	0,24	0,85	10	2,00	0,72	1,44
9	3,52	0,16	0,56	8	4,14	0,16	0,66	9	4,14	0,26	1,08	8	2,85	0,50	1,43
7	2,00	0,81	1,62	6	3,12	0,72	2,25	7	3,12	0,68	2,12	6	3,45	0,91	3,14
5	0,90	3,24	2,92	4	1,58	2,61	4,12	5	1,58	2,56	4,04	4	2,13	2,72	5,79
3	0,40	5,40	2,16	2	0,66	5,00	3,30	3	0,66	5,00	3,30	2	1,05	5,00	5,25
1	0,10	7,40	0,74	0	0,20	7,10	1,42	1	0,20	6,80	1,36	0	0,30	6,80	2,04
			9,89				14,23				15,99				25,41
½ dist. between w. lines			1,185				1,185	½ dist. between w. lines			1,185				1,185
Sum of the effects. .. =			11,72				16,86	Sum of the effects.... =			18,95				30,11
Total effect .... =			11,72 + 18,86 = 28,58					Total effect .... =			18,95 + 30,11 = 49,06				

TABLE No. 24.—(*continued.*)

Force of Cohesion abaft the ⊕ Section.

Between the 7th and 8th Water-line.

Triangle No.	Base of Triangle.	Force of Cohesion.	Force multiplied by the Base.	Triangle No.	Base of Triangle.	Force of Cohesion.	Force multiplied by the Base.
23	—	—	—	22	—	—	—
21	0,33	1,00	0,33	20	0,20	2,80	0,56
19	0,50	1,82	0,91	18	0,33	3,33	1,10
17	1,07	2,00	2,14	16	0,63	3,72	2,34
15	1,30	1,60	2,08	14	0,74	3,30	2,44
13	1,60	1,36	2,18	12	0,90	2,93	2,63
11	2,00	1,36	2,72	10	1,00	2,93	2,93
9	2,85	1,15	3,28	8	1,30	2,60	3,38
7	3,45	1,35	4,65	6	1,53	3,00	4,59
5	2,13	2,98	6,35	4	1,50	4,26	6,39
3	1,05	5,00	5,25	2	1,85	6,06	11,21
1	0,30	6,80	2,04	0	0,20	7,50	1,50
			31,93				39,07
½ dist. between w. lines			1,185				1,185
			37,84				46,30

Sum of the effects... = 37,84
Total effect .... = 37,84 + 46,30 = 84,14

Below the 8th Water-line.

Triangle No.	Base of Triangle.	Force of Cohesion.	Force multiplied by the Base.
21	0,20	2,83	0,56
19	0,33	3,30	1,10
17	0,63	3,90	2,46
15	0,74	3,60	2,66
13	0,90	3,34	3,01
11	1,00	3,34	3,34
9	1,30	3,50	4,55
7	1,53	4,05	6,20
5	1,50	4,86	7,29
3	1,85	6,06	11,21
1	0,20	6,90	1,38
18	0,13	6,80	0,88
16	0,24	6,07	1,46
14	0,26	6,00	1,56
12	0,27	6,00	1,62
10	0,27	6,30	1,70
8	0,23	6,60	1,52
			52,50
½ dist between w. lines			1,185
Total effect........ =			62,22

RECAPITULATION.

Between 1st and 2nd =	251,06
2nd and 3rd =	166,58
3rd and 4th =	72,97
4th and 5th =	30,25
5th and 6th =	28,58
6th and 7th =	49,06
7th and 8th =	84,14
Below the 8th...... =	62,22
Resistance on the sternpost & rudder =	67,68
Total cohesion ..... =	812,54
Total resist. forward =	4772,87
Total .... =	5585,41

Which is the total effect in opposing the course of the ship.

In the same manner, the effect of the water in opposing the motion of all the other ships is found, the calculations of which it is unnecessary to insert here; the results only are given, which are inserted in the following table:—

TABLE No. 25.

Between the WATER-LINES.	110		94		80		74		66		52	
	Resistance forward.	Cohesion abaft.	Resistance forward.	Cohesion abaft.	Resistance forward.	Cohesion abaft.	Resistance forward.	Cohesion abaft.	Resistance forward.	Cohesion abaft.	Resistance forward.	Cohesion abaft.
1 and 2	1213,24	370,06	1075,01	316,78	968,09	272,95	901,42	251,06	861,39	234,67	688,87	154,24
2 and 3	1134,96	260,60	1010,24	221,33	903,66	186,71	840,28	166,58	796,47	149,58	630,20	61,49
3 and 4	1046,13	130,49	924,30	111,42	827,70	91,69	766,32	72,97	725,96	61,68	570,76	26,48
4 and 5	930,77	39,89	818,22	38,45	729,38	36,66	671,98	30,25	636,03	28,55	501,69	21,62
5 and 6	812,69	31,11	706,26	26,39	625,53	30,21	575,21	28,58	536,14	29,30	412,73	29,62
6 and 7	643,74	54,61	549,15	67,93	483,25	51,44	449,42	49,06	409,13	49,93	303,53	46,02
7 and 8	418,43	105,55	351,13	92,35	306,78	85,65	286,97	84,14	255,94	73,44	182,25	61,27
Below 8	146,43	80,16	108,15	67,01	102,85	62,33	93,13	62,22	83,91	53,68	69,54	41,46
Stem and rudder.......	257,76	96,80	240,51	83,68	202,93	77,60	188,14	67,68	179,95	64,80	150,00	55,00
Total........	6604,15	1169,27	5782,97	1025,34	5150,17	895,24	4772,87	812,54	4484,92	745,63	3509,57	497,20

As it cannot be clearly seen from these numbers how the effect of the water diminishes, according to the form of the ship, from the upper water-line to the keel, the figures 76, 77, 78, &c. are drawn in this manner: the horizontal lines 1, 2, 3, &c. on each figure represent the water-lines, and on the ticked lines between the water-lines is set off the $\frac{1}{100}$ part of the effect which is found in the tables, as well of the resistance forward, on the right side, as of the cohesion abaft, on the left side of each figure. Fig. 76 represents the effect of the water on a ship of 110 guns; Fig. 77 on a ship of 94 guns; Fig. 78 on a ship of 80 guns; Fig. 79 on a ship of 74 guns; Fig. 80 on a ship of 66 guns; and Fig. 81 on a two-decked frigate. The same calculations are also made for a French ship of 120 guns, the *Sans Culotte* (Fig. 82), and for an English ship of 74 guns, the *Brunswick* (Fig. 83). From this it may be seen what effect, especially on the after-part, fulness or great sharpness, produces, in retarding a ship's progress.

Thus the resistance is found, which a ship experiences in its course; namely, the opposing force which the water exerts on its bow, and the force of cohesion of the water abaft, which opposes the ship and retards its course, in proportion to its force. As it is both these forces which jointly retard a ship's motion, it follows that they must be added together, and be given the general name of the *resistance of the ship*, which is found in the following table for each ship.[1]

TABLE No. 26.

	110	94	80	74	66	52	Sans Culotte 120	Brunswick 74
Resistance of the w. forward	6604	5783	5150	4773	4485	3509	7435	5334
Force of cohesion abaft	1169	1025	895	813	746	497	1695	1305
Resistance of the ship on one side.......... = R	7773	6808	6045	5586	5231	4006	9130	6639

(*To be continued in the next Number.*)

[1] Suppose that the ship is not diminished at the extremities, but retains the form of the ⊕ section from one end to the other; then it will be found that the effect of the water abaft in retarding the ship's course, is in this case something more than one-third of the resistance forward; hence it follows, that the problem *of the resistance bodies experience from the water* is not correctly solved, if the expression does not clearly show the effect of the water separately for each end.

ART. XIX.—*A Mode of fixing the Paddles of Steam Vessels, so as to prevent tremulous Motion. By* MR. WM. HENWOOD, of his Majesty's Dock-Yard at Portsmouth.

DURING a passage on board the *Brunswick* steam-vessel, from Plymouth to Portsmouth, in July 1828, the unpleasant sensation experienced from the tremulous motion of the vessel led to a consideration of the cause of this motion. It soon appeared to the writer that it was caused principally, if not entirely, by the successive and distinct impulses of the paddles against the water; and that if the number of paddles on a wheel could be indefinitely increased, so that there would be an indefinitely small interval or space between them, there would in all probability be no tremulous motion.

About a fortnight subsequently to this period, whilst perusing a Memoir on a new system of cog or toothed wheels, by the late Mr. James White, of Manchester, in his "New Century of Inventions," it occurred to the writer, that if the principle of those cog-wheels could be adopted in the construction of the paddle-wheels of steam-vessels, the tremulous motion would be totally annihilated. This idea was made known a few days afterward to the conductors of "Papers on Naval Architecture," and to two or three other persons; and it was not until August last the writer was informed the paddle-wheels of the *Brunswick* had been fitted in a similar manner, and that they had been found to render the motion of the vessel through the water uncommonly smooth and easy, without occasioning a considerable, if any, loss of velocity.

It is stated by Tredgold, in Partington's account of the steam engine, page 272, that "The best position for the paddles appears to be in a plane passing through the axis (of the wheels); if they be in a plane which does not coincide with the axis, they must either strike more obliquely on the fluid in entering, or lift up a considerable quantity in quitting it. With respect to the shape of the paddle, it is clear that it should be such that the resistance to its motion should be the greatest possible, and the pressure behind it the least possible. These conditions appear to be fulfilled in a high degree by the sim-

plest of all forms, the plane rectangle; but we might learn much from a judicious set of experiments on this subject." Until Mr. White had so strikingly shown the contrary, it was universally thought that the best position for a tooth of a cog-wheel was in a plane coincident with the axis; or, which is the same thing, that the teeth should be parallel to the axis. It will be endeavoured to show that, all things considered, the best way of placing the paddles of steam-vessels is oblique with respect to the axis of the wheels.

Assuming that the tremulous motion is produced solely by the impulses of the paddles against the water, it must be admitted to be impossible that the tremulous motion can be removed whilst there exists an interval, however small, between the successive strokes of the paddles. It is considered there can be no other way of getting rid of this interval, than by placing the paddles at such an angle of inclination to the axis, that the outer end of one paddle shall be in the same athwart-ship plane with the inner end of the next; so that at the instant a paddle has passed any given transverse plane, the succeeding paddle shall have arrived at that plane. The interval between the successive strokes of the paddles being reduced to nothing by placing the paddles at the requisite angle of inclination to the axis, the whole force of the resistance of the paddles against the water must be continually the same, and the moving power of the wheels must be perfectly uniform and equable.

The form of these paddles is obviously not that of 'a plane rectangle,' because all lines drawn on them in planes at right angles to the axis of the wheels are radii of the wheels. The surface of each paddle accordingly will not be a plane, but a curved surface, and of a spiral or screw form.

As the paddles by being placed obliquely would of course be driven more easily through the water than when placed in the usual manner, it is proper to inquire whether the motion of a vessel would be considerably retarded in consequence of the obliquity of the stroke of the paddles against the water. It appears, from Art. 34, Vol. I. of this Work, that the general rule for placing the paddles is to divide the circumference of the wheel in such a manner that there may be as many paddles as

the diameter of the wheel contains linear feet. Assuming accordingly that the distance between the paddles should generally be about three feet, and that the wheels may be about eight feet broad, the angle which an oblique paddle would form with a plane passing through the axis of the wheels would be about $20\frac{1}{2}°$. The resistance of a paddle placed at an inclination of $20\frac{1}{2}°$ to the axis, calculated according to the common theory of resistances, would be about 0,82 of that of a common paddle, if both were fixed on the same wheel. And the whole resistance of a wheel with oblique paddles would be about 0,82 of that of a wheel of the same size with common paddles, if both were moved with equal velocities. But if the wheels of one steam vessel were to be fitted with oblique paddles, and those of another vessel of the same form and dimensions, and similarly circumstanced in every respect, with common paddles, as the resistance of both vessels to motion would be the same, and the power of the engines to turn their wheels the same in both, the wheels with oblique paddles would be turned faster than those with the common paddles, and thus the whole resistance against the water of the wheels with oblique paddles, would, it is probable, be very much more than 0,82 of that of the wheels with common paddles. And as the velocity of a vessel is proportional to the square root of the resistance to her motion, the velocity of the vessel with oblique paddles would probably be very much greater than nine-tenths of that of the vessel with common paddles. It thus appears to be highly probable that a considerable sacrifice of velocity would not be incurred if the wheels of steam-vessels were to be made of the same breadth as at present and fitted with oblique paddles; and of course, if the wheels were to be made a few inches broader, or if the power of the engines were to be increased in a small degree, the whole effect of wheels with oblique paddles would be quite as great as with common paddles; and it is certain the tremulous motion caused by the distinct impulses of the paddles against the water, would be wholly removed.

An advantage of this method of oblique paddles over other methods which have been proposed is, that the paddles can be fitted with the same facility and firmness as common paddles;

the only difference being that the boards must be sawed with the requisite curve and winding, as it is technically called, instead of being cut straight. Of the expediency of getting rid of the tremulous motion, it may be observed, that it would render steam-vessels a much more agreeable means of conveyance than they have been hitherto; and it is not improbable that this incessant jarring motion is in some degree detrimental to the strength of their hulls, and that it would be especially so to the hulls of steam-vessels of war, on account of the great weights of their armament.

ART. XX.—*A Method of computing the Tension of Ropes; applied to determine the Strain in Experiments similar to those by which Anchors, &c. have lately been tried in Portsmouth Dock-yard.* By Mr. GEORGE COURTNEY, of His Majesty's Dock-yard, Portsmouth.

EXPERIMENTS on a very large scale are frequently instituted in Portsmouth dock-yard, in which anchors and other articles of great magnitude are tried against each other, to compare the strength produced by various modifications of their construction or manufacture. Not long since two anchors were thus tried, one, constructed by Lieut. Rodger, R. N., on a principle for which he has taken out a patent; the other, the anchor commonly used in the service, and manufactured on the principle of Mr. Pering. Very recently also a comparison was made between two methods of connecting a chain to a hempen cable, one, by splicing them together with chain tails, as is at present the case; the other, by splicing an eye in the end of the cable, and uniting it to the chain by a connecting link, according to a plan proposed by the Honourable Captain Elliot. In each of these cases the superiority of one anchor, or one mode of connection, was clearly manifested by the breaking of its antagonist.

These experiments, however, would certainly be rendered more valuable, if the exact strain existing at the moment of breaking were correctly ascertained; and a more complete

knowledge of the merits of the articles compared would be acquired by breaking them in succession, and comparing the strains necessary to effect this. An easy method of computing these strains is the subject of this paper.

It will be previously necessary to give a short description of the manner in which these experiments (those on anchors for example) are conducted.

A part of the yard is selected where two storehouses are erected immediately opposite to each other, and separated by a narrow road. A strong beam of timber is laid across each end of the road, and resting against the walls of the storehouses. To these beams the anchors are hooked by their palms, their rings being placed towards each other. To the rings two treble blocks are lashed, through which tackles are rove, to which other tackles are applied, and the falls led away to capstans which are hove round till one of the anchors is broken.

Let AB (Fig. 84) be one of the parts of the main purchase, lying between A and B two of the sheaves of the blocks. Bisect AB in C, and draw CD perpendicular to AB in a plane parallel to the horizon; at any point D in CD let a pulley be fixed, over which let a cord be passed, having one end fixed to AB at C, and the weight W attached to the other, and hanging freely down. The point C of the cord ACB will be thus drawn in the direction CF, till an equilibrium subsists between the tensions of the cords AF, FB, and FD. Let AFB be the position of equilibrium, and complete the triangle of forces AFH, then,

$$\text{tens. } AF : \text{tens. } FD :: AF : FH$$

$$:: (AF + FB) : 2FH$$

or, substituting $W = \text{tens. } FD$; and $4FC = 2FH$

$$\text{tens. } AF : W :: (AF + FB) : 4FC$$

$$\text{therefore, tens. } AF = \frac{W \times (AF + FB)}{4FC}$$

$$\text{or, tens. } AB = \frac{W \times AB}{4FC} \text{ very nearly.}$$

Now if AB be that part of the tackle which lies equally between the standing and running parts, and n be the whole number of parts, $n \times$ tens. AB is equal to the whole effort of the tackle; therefore,

$$\text{the whole effort} = n \times \frac{W \times AB}{4\,FC}.$$

In which expression substituting the proper values for the constant quantities n, W, and AB, and for the variable quantity FC, which must be observed at the time of the experiment, the whole effort of the tackle will be found. It is manifest that no correction will be required on account of friction.

It may be suggested that there are collateral advantages to be derived from these experiments without interfering with their main purpose.

1st. A valuable set of experiments on the deflection of timber of large dimensions would be obtained, by employing timbers of different species and dimensions in each successive trial.

2nd. The friction caused by pulleys may be investigated by applying weights to each part of the tackle, and thus estimating the tension of each part.

The tension of shrouds may also be regulated in this manner, and the weight of masts ascertained when suspended from the sheers.

Art. XXI.—*On the Metacentre and Metacentric Curve.* By Mr. Samuel Read, of his Majesty's Dock-yard at Chatham.

By pursuing a train of reasoning similar to that which Atwood has employed, and which may be seen in the "Philosophical Transactions" of the Royal Society for 1796 and 1798, we shall have the moment of stability of a floating body expressed by the general equation.

$$GZ \times V = bA - dV \sin. \triangle$$

where V represents the volume of displacement: A the volume of immersion or emersion at the given angle ($\triangle$) of inclination

or heeling; b the horizontal distance between the centres of gravity of the volumes immersed and emerged; GZ the perpendicular drawn from the centre of gravity of the floating mass to the line of support; and d the distance between the centre of gravity and the centre of buoyancy corresponding to the upright position.

Now supposing Δ to be indefinitely small, and that the vertical transverse sections of a vessel are similar and equal with respect to the longer axis, the common section of the inclined water-line with that corresponding to the upright position will coincide with the middle line of the latter plane, and consequently the areas of immersion and emersion in the vertical transverse sections may be considered as equal isosceles triangles. With these circumstances in remembrance let $WATBF$ (Fig. 85) be a vertical transverse section symmetrical with regard to its axis TG, in which are the centre of gravity G and centre of buoyancy D; and let the line of support QM cut the diametrical section, passing through TG at right angles to the plane of $WATBF$, in the point M above G, the water's surface coinciding with the line AB: put the breadth $AB = t$; then in the general expression just given we shall have,

$$A = \frac{t^2 \sin. \Delta}{8} \text{ and } b = \frac{2\,t}{3}$$

$$\text{hence, } GZ \times V = \frac{t^2 \sin. \Delta}{8} \times \frac{2\,t}{3} - dV \sin. \Delta$$

$$\therefore GZ = \frac{t^3 \sin. \Delta}{12\,V} - d \sin. \Delta$$

the same value as that obtained for GZ in Atwood's 10th case, where the vertical transverse sections are equal circles.[1] Again,

$$GM = \frac{GZ}{\sin. \Delta} = \frac{t^3}{12\,V} - d$$

$$\text{and } DM = GM + d = \frac{t^3}{12\,V}$$

[1] Philosophical Transactions, 1798.

The point M, whose position is indicated by the last expression, is called the *Metacentre;*[1] and supposing the point G to move upwards in the line TGM produced, is evidently the point in its motion at which the equilibrium of stability becomes insensible, and is then succeeded by a state of instability, when a spontaneous change of position of the floating mass will ensue until the relative situation of the points M and G are such as again to produce the state of stability.

When the point G is below the point M, the value of GZ in the above expression is positive; when the same point coincides with the point M we have $GZ = zero$; and if G be above M, the line GZ becomes negative; it may therefore be generally concluded that the *line GZ drawn from the centre of gravity of the vessel perpendicular to the line of support is positive, zero, or negative, accordingly as the state of stability, insensibility, or instability, obtains.*

It is evident from the last expression but one, that GM varies as GZ, and may therefore be regarded in the case before us as a measure of the stability instead of GZ. Consequently, when the point G coincides with the point D, the height DM may be taken as the measure of the stability.

To obtain a formula for the height of the metacentre in a vessel whose vertical transverse sections and breadths vary at the water's surface, we may proceed as follows.

Let x be any variable portion of the length measured on a line passing through the water-section so as to divide it into two equal and symmetrical parts, and let y be the variable half breadth or semi-ordinate of the water-section corresponding to the length x: then we have the triangles of immersion or emersion in this case, each equal to $\frac{y^2 \sin. \Delta}{2}$, and the evanescent solids immersed and emerged each equal to $\frac{y^2 \sin. \Delta \, dx}{2}$. Now the centre of gravity of each of these very small prisms may be considered as at a horizontal distance from x equal to $\frac{2y}{3}$

[1] Bouguer, Traité du Navire.

and therefore their moments with respect to x will each be equal to $\frac{y^2 \sin. d x}{2} \times \frac{2 y}{3} = \frac{y^3 \sin. \Delta}{3}$. Hence putting as before the volume immersed or emerged $= A$, the distances of the centres of gravity of the volumes immersed and emerged from x being each equal to $\frac{\int y^3 \sin. \Delta \, d x}{3 A}$, the horizontal distance between the same two centres will be equal to $\frac{2 \int y^3 \sin. \Delta \, d x}{3}$ and the expression $G Z \times V = b a - d \sin. \Delta \, V$ becomes, by substituting for b the value just found,

$$G Z \times V = \frac{2 \int y^3 \sin. \Delta \, d x}{3} - d V \sin. \Delta$$

$$\text{or } G Z = \frac{2 \int y^3 \sin. \Delta \, d x}{3 V} - d \sin. \Delta$$

$$\therefore G M = \frac{G Z}{\sin. \Delta} = \frac{2 \int y^3 \, d x}{3 V} - d$$

$$\text{and } D M = \frac{2 \int y^3 \, d x}{3 V}$$

The two formulæ $G M = \frac{t^3}{12 V} - d$ and $G M = \frac{2 \int y^3 \, d x}{3 V} - d$ are principally of use to determine whether floating bodies will sustain themselves permanently in the upright position or spontaneously upset; but the second formula has been considered by most authors who have treated on the theory of naval architecture to be a sufficient criterion of the stability of a ship; not only at evanescent, but also at finite, angles of heeling. It is vain, however, to conceal that the conditions on which this expression is founded do not justify such an extension of its use, and the most vexatious disappointments have repeatedly punished those who have relied implicitly on assurances thus illegitimately obtained from it, regardless of the cautions of its discoverer, the talented Bouguer. The naval

architect will not need in this place a particular account of such proofs of the insufficiency of the metacentric theory as usually applied to ships: the history of his art and his own recollections will afford this; but to the more general reader we would recommend the perusal of the *facts* related by Romme in his "*L'Art de la Marine,*" and which have been detailed in "Papers of Naval Architecture," at page 62, vol. I.

Let the curve $E\,t\,t'\,T$ (Fig. 86) be the locus of the centre of buoyancy during successive indefinitely small inclinations from the upright; the centre of buoyancy in that position being in the point E in the vertical axis $E\,X$ of the transverse section passing through the centre of gravity. Let the water-line $a\,b$ be that corresponding to the first inclination; $a'\,b'$ that corresponding to the second, and so on. Suppose the evanescent portion $E\,t$ of the curve $E\,t\,t'\,T$ to be contemporary with the water-line $a\,b$; draw $t\,M$ perpendicular to the curve at t and intersecting the vertical axis $E\,X$ in the point M: this point will be the metacentre corresponding to the upright position. Let another very small portion $t\,t'$ of the curve be taken contemporary with the water-line $a'\,b'$: draw $t'\,m$ perpendicular to the curve at t' and let it intersect $t\,M$ produced in the point m, which will be the metacentre corresponding to the water-line $a\,b$; and in the same way may m' and other points be found, m' being the metacentre corresponding to the water-line $a'\,b'$. Now since the points M, m, &c. are determined by the intersections of the perpendiculars to the curve $E\,t\,t'\,T$ at the very small intervals $E\,t$, $t\,t'$, &c. it follows that they are centres of curvature to the same curve: consequently these points must be in the evolute of the curve $E\,t\,t'\,T$. This evolute is termed by Bouguer the *metacentric curve.*[1]

As the leading property of the curve $E\,t\,t'\,T$, described by the centre of buoyancy is, that its tangents are always parallel to the water's surface corresponding to the touching point, it is evident that its radii of curvature always coincide with their contemporaneous lines of support.

The *metacentric curve,* and *not* the *metacentre,* has been

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[1] The curve described by the centre of buoyancy might, for the sake of distinction, be called the *metacentric involute.*

considered by its author, M. Bouguer, to indicate whether, at a *finite* angle of heeling, a floating body is secure from upsetting, in which case the metacentric curve *rises* as the body inclines; and on the contrary, if during the inclination the metacentric curve *descends*, the body is deemed to be insecure.

We shall presently endeavour to explain how far the properties of the metacentric curve justify the conclusions just mentioned. M. Bouguer asserts them without any demonstration,[1] which M. Clairbois has attempted to supply,[2] by the investigation of two cases similar to cases 6 and 7 given by Atwood in his examination of the subject.[3] In the first of these two cases, viz. when the vertical transverse sections of a vessel coincide with the sides of an isosceles triangle, placed with the vertex downwards, Clairbois shows that the metacentric curve rises as the inclination increases, and causes the radii of curvature of the *metacentric involute* to cut the vertical axis of the body at points progressively ascending, whilst the radii themselves elongate. In the second case, or when the same body is so placed that the vertex of the transverse section is upwards, he says, that the metacentric curve *descends*, and consequently that the body will upset, at a certain inclination, when the line of support passes below the centre of gravity. This last conclusion, however, viz. that the metacentric curve descends when the vertex of the triangle is above the fluid, is incorrect, for it will be found, on strict examination, that the locus of the successive metacentres will *rise* in this case also.

Whilst it is difficult to conceive how any person moderately conversant with geometrical investigation, or at all sensible of its inflexible character, much less such an eminent geometer as Bouguer, could have relapsed into such a loose method of deriving results as Atwood seems to insinuate has been the fact with regard to the metacentre; it is also very surprising how the latter-mentioned author could have read the "*Traité du Navire*," and the palpably erroneous discussion of the

[1] Traité du Navire, p. 269 and following pages.

[2] Essai Geometrique sur l'Architecture Navale, p. 289 and following pages.

[3] Philosophical Transactions for 1798.

question given by Clairbois, without immediately detecting the cause of the discrepancy which he ultimately assumes to exist between his own conclusions and those of the inventor of the metacentric theory. But neglecting, for the present, any further remark on the error into which Atwood has undoubtedly fallen by a too implicit reliance on Clairbois' illustration of Bouguer's principles, we shall proceed to show where the deductions of M. Clairbois are true and where false.

It will not be necessary here to follow strictly M. Clairbois' method of treating the subject, more particularly as his analysis is very much encumbered and tedious to follow in some parts. We shall point out by a much shorter and equally legitimate method, that *instead of the successive radii of curvature of the metacentric involute ascending in the first, and descending in the second, of the cases under consideration*, as he pretends; *they will ascend in both cases.*

Let AB (Fig. 87) be the water-line, when the isosceles wedge $MACBF$ is floating in the upright position; and imagine the body to be inclined until the water's surface coincides with the line ab; observing that the angle F is not immersed. Now as the volume of displacement remains unaltered, the areas aCB and ACB are equal to one another. Bisect ab in the point d, also bisect AB in the point D: then, by the property of the hyperbola, d and D will respectively be the points of contact of an hyperbola with its tangents ab and AB; AC and Cb being the assymptotes, and D the vertex, of the curve. Join CD, which being (from the hypothesis) perpendicular to AB, will be the axis of the curve dD. It appears, therefore, that the water-line in every position of the body will be a tangent to this hyperbola, and that the infinitely small portion of the tangent at the successive points of bisection will coincide with the hyperbola. But as the centre of buoyancy moves parallel to the water's surface during each infinitely small inclination, it will also move in an hyperbola Ee,[1]

[1] That the locus of the centre of buoyancy is, in this case, an hyperbola may also be proved as follows:—

Let ZVH (Fig. 89) be an isosceles triangle floating in the upright position, with the vertex V downwards, and the water's surface coinciding with the line

and if perpendiculars be drawn to one of these curves, they must be parallel to those drawn to the other, supposing the points from which they proceed in the two curves to be contemporaneous. Hence, if the perpendiculars to either curve cut the axis of the figure in points which progressively ascend as the body inclines, it results that the contemporaneous per-

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AB. Let this triangle be inclined, so that the water's surface may coincide with the line CH, cutting off the area CVH equal to the area AVB immersed by the inclination. Bisect AB and CH in K and r respectively, and join VK (which will coincide with the vertical axis of the triangle) and Vr. Take $VD = \frac{2}{3} VK$ and $VT = \frac{2}{3} Vr$; then D and T will be points in the metacentric involute, D being clearly the vertex of the curve. Let L and M be the respective centres of gravity of the triangles immersed and emersed: through T, r, L, M, and H, draw TF, ba, LQ, MP, and Hk parallel to AB; ba intersecting VK produced in m, and LQ and MP intersecting CH in Q and P. Draw Hp, Ch, LW, QR, MG and PN perpendicular to AB; Hp meeting ba produced in p, and Ch prolonged meeting Hk in k. From this construction it is evident that the triangles Hap and Chb are similar and equal, and consequently that $ba = hp = Hk$. Call $FT = y$ and $DF = x$, then the distance between M and L estimated in the directing DF of x is $MG + WL$, and the distance between the same points estimated in the direction FT of y will be $GS + SW$; but,

$$MG + WL = PN + RQ = \frac{CH \sin. \Delta}{3}$$

Δ being as usual put equal to the angle of inclination. Also,

$$GS + SW = \frac{AB}{3} + \frac{CH . \cos. \Delta}{3}$$

and calling the displaced volume $= V$, and the volume of immersion emersion $= A$, we have,

$$V.x = \frac{A . CH . \sin. \Delta}{3}$$

$$V. y = A \times \left\{\frac{AB}{3} + \frac{CH. \cos. \Delta}{3}\right\}$$

$$\text{Hence } y = \left\{\frac{AB \cdot x}{CH \cos. \Delta} + x\right\} \frac{1}{\tan. \Delta}$$

$$\text{but } CH . \cos. \Delta = Hk = ab$$

$$\therefore y = \left\{\frac{AB . x}{ab} + x\right\} \frac{1}{\tan. \Delta}$$

$$\text{or, } y = \left\{\frac{VK . x}{Vm} + x\right\} \frac{1}{\tan. \Delta}$$

and as $VD = \frac{2}{3} VK$, and $VF = \frac{2}{3} Vm$, we have,

pendiculars of the other will do the same, and as the action upwards of the fluid, concentrated in the centre of buoyancy, takes place in lines successively perpendicular to the metacentric involute, the body will be restored with a power which will increase at each addition to the deflection from the upright position.

Let us therefore examine if, in the figure before us, the perpendiculars to the curve $D d$ cut the axis $C D R$ in points more elevated as the point d (from which any perpendicular $d R$ is drawn) recedes from the vertex D. Now $d R$ is the normal to the curve at the point d: draw the ordinate $d P$ perpendicular to $D R$, then $D R$ (putting $P D = x$) $= x +$ the sub-normal. Put $d P = y$; the semi-axis major $= a$; and the semi-axis minor $= b$: then the subnormal $= \frac{b^2}{a^2} \times \overline{a + x}$ and $D R =$ $\frac{b^2}{a} + \frac{b^2 + a^2}{a^2} \times x$, an expression which shows that whilst the

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$$y = \left\{\frac{VD \, . \, x}{VF} + x\right\} \frac{1}{\tan. \Delta}$$

or putting $VD = a$,

$$y = \left\{\frac{a x}{a + x} + x\right\} \frac{1}{\tan. \Delta} = \frac{2 a x + x^2}{a + x} \times \frac{1}{\tan. \Delta}$$

But $\frac{2 a x + x^2}{a + x}$ is the subtangent of the hyperbola whose centre is in the point V, hence, take $F E = \frac{2 a x + x^2}{a + x}$, and join $T E$, which will be the tangent to the curve at the point T, and will make the angle $F T E = \Delta$.

Cor. 1. When the vertex of the triangle is upwards, as in Fig. 88, and the breadth at the water's surface is the same as when the vertex is downwards; it will appear from a slight consideration, that as the values of y and x, at the given angle of inclination, are not changed by the new position of the figure, the curve described by the centre of buoyancy will be the *ascending* branch of an hyperbola similar and equal to the *descending* hyperbolic branch described, on the other side of the axis, by the centre of gravity of the constant area $a\,C D$ above the water's surface.

Cor. 2. When the vertex V is situated at an infinite distance below the water's surface $A B$, or the sides $H V$, $B V$ are parallel to the vertical axis, we have the equation $y = \frac{2 a x + x^2}{a + x} \times \frac{1}{\tan. \Delta}$ become $y = \frac{2 x}{\tan. \Delta}$ which shows that the metacentric involute is then the common parabola, and the metacentric curve itself the semi-cubical parabola,

value of x increases, that is, the further the point d is taken from D, the height DR will also be augmented. Hence, the lines of support eQ drawn from the curve traced out by the centre of buoyancy will, at successive inclinations, intersect the axis CR at points progressively ascending; and if the centre of gravity G of the body be once below the line of support, it will always be below it.

Let us now take the body CFM and reverse its position, as in Fig. 88, so as to have the vertex C upwards, and the surface of the water corresponding to the upright position coinciding with the line AB, and that of the inclined position to the line ab; then, as the volume of displacement remains constant, the areas $AMFB$ and $aMFb$ respectively corresponding to the water-lines AB and ab will be equal to each other, and consequently the area CAB equal to the area Cab: hence, as in the other case, the lines AB and ab will touch an hyperbola whose assymptotes are CM and CF and vertex D. Now the branch Dd of the hyperbola tends downwards, and the perpendicular dR at any point d of the curve will cut the axis below the surface of the water in some point R; and by the property that we have just developed, the point R will progressively descend as the point d recedes from the point D, or as the body inclines. Let E be the centre of buoyancy: this point will, as before, trace out an hyperbola; but with its branch Ee directed upwards and on the other side of the axis DR.[1] Now M. Clairbois says, that if the points of intersection of successive perpendiculars dR with the axis DR progressively descend as the point d recedes from the vertex D, the intersection of the contemporaneous perpendicular to the curve Ee, with the same axis, must fall likewise: this is a manifest error; for it has just been proved that the perpendiculars to an hyperbola (situated as the curve Ee) will, as they are drawn from the more distant points of the curve, cut the axis in points progressively *ascending*. In fact the intersecting points made by the latter perpendiculars with the axis *ascend* for the same reason as those made by

[1] See note p. 295, concluding paragraph.

the perpendiculars of the curve Dd descend. Thus it appears, contrary to the deduction of M. Clairbois, that in this case if the centre of gravity be once below the line of support it will always continue so, and the body will be secure from upsetting. Therefore the true comparison we have instituted between M. Clairbois' two cases leads to an inference, which is *not incompatible* with that derived by Mr. Atwood from the investigation of his 6th and 7th cases.

In drawing this memoir to a close, it is but doing justice to M. Bouguer to say, that in page 272 of the "*Traité du Navire*," it most distinctly appears from the following passage, that he did not regard the metacentric theory in the manner attributed to him by Mr. Atwood.

"Si les deux flancs OE et CE (Fig. 90) de la carène sont des lignes droites qui forment un angle en E, ou plus généralement, si les deux flancs sont formér par une hyperbole, dont E est le sommet, les centres de gravité de toutes les parties submergées, formeront une hyperbole; et sur ce qu'on sait de la dévelopée de cette courbe, on peut assurer que la poussée de l'eau s'exercira sur des directions qui couperont l'axe EZ dans des points toujours plus élevés; et qu'ainsi cette puissance acquirera de plus en plus une plus grande force relative pour s'opposer à l'inclinaison, ou pour relever le navire."

And at page 274 of the same work, it is still more evident that he was fully acquainted with the true principles by which the metacentric curve indicates the safety or danger of a floating body when inclined at a finite angle from the upright position, and moreover shows that the greatest breadth should be continued for some distance above and beneath the plane of floatation, in order to ensure the rising of the metacentric curve as the vessel heels. For the satisfaction of the reader we subjoin the original passage, which, after some observations on the practice, even now generally existing, of placing the main breadth of a ship at, or a little above, the plane of floatation, proceeds, "Mais qu'on doit faire ensorte que la carène augmente de largeur, ou qu'élle conserve au moins la même jusqu'à l'endroit où elle enforce dans l'eau, lorsque le navire s'incline le plus. L'inclinaison peut aller jusqu'à 10 ou 12 degrez, et même plus loin dans les petits navires, lorsque le vent charge

les voiles avec force. Nous souhaiterions donc que la partie *A A'* des flancs du vaisseau qui est alors sujette à entrer dans la mer, et qui est de 4 ou 5 pieds dans les vaisseaux du premier rang, et de 3 ou 4 dans les navires de deux à trois cens tonneaux, ou fut presque droite, ou qu'elle eut quelque saillie en dehors; et que ce ne fût qu'au-dessus du point *A* que le flanc commençât à rentrer en-dedans, et le navire à se retrecir. Par ce moyen la courbe *T H* deviendroit à peu pres une hyperbole, ou au moins une parabole vers les deux extrémités, et la branches *g M*, *g N* de la metacentrique *N g M* qui en seroit la developée, iroient en montant au dessus du metacentre *g*. Toutes les fois que l'inclinaison augmenteroit, le centre de gravité du vaisseau s'écarteroit ensuite de la direction *H P* de la poussée de l'eau, pendant que cette direction s'eloigneroit en son particulier de ce centre par son progrès vers le côté de l'inclinaison; et tout contribueroit donc à rendre plus long le bras du levier auquel est appliquée cette force avec laquelle l'eau pousse continuellement en haut."

Art. XXII.—*A proposed Improvement in the Steering Wheel for Ships which have their Tillars worked on the Quarter-deck, with some general Remarks on the Steering of Ships. By* William Henry Harton, Esq., of Limehouse, formerly of the Honourable East India Company's Service.

It has of late years been thought necessary, even in ships of eight and nine hundred tons burden, for the sake of stowage and other reasons, to bring the wheel and tillar on the weather-deck, by lengthening the rudder head, or by fitting an iron spindle; the tillar being reduced from 12 or 14 feet to half that length, and worked by a whip purchase. By this plan the sweep is done away with, but the wheel and barrel remain; however, the alteration, compared with the old and simple mode of steering below, with a sweep and single rope, is accompanied with serious inconvenience in two respects. First, the leading blocks are brought so close to the barrel of the wheel, that in putting the helm hard over, either way, the angle

formed by the ropes is so great that they not only chafe very much, but actually ride over the turns on the barrel, rubbing at the same time against the jaws of the leading blocks. The effect of this is, that the ropes are not only rendered in a short time useless, but the friction caused in working is so great that it adds in no small degree to the labour of the helmsman. In order to rectify this inconvenience, the following method of fitting the wheel is proposed. Fig. 91 represents a fore and aft elevation of a steering wheel, with the stantions, deck, and leading blocks; Fig. 92 is an improved axis for the wheel, having its after end *ef* formed into a screw, the distance between two contiguous threads of which must be equal to the diameter of the wheel rope; this screw is to work in a nut *g* fixed in a cleat brought on the after side of the after stantion. The screw *ef* must be of such a length, that by working in the nut *g* it will be capable of a fore and aft motion in the barrel, sufficient to admit of the wheel ropes always preserving a perpendicular direction over the leading blocks; by which means all chafing against the jaws of the blocks will be avoided; and from the ropes always leading at right angles to the spindle of the wheel, the extra friction occasioned by one turn bearing hard against or riding over the other, as the ropes pass round the wheel, in the action of steering, will be altogether prevented. This will very sensibly facilitate the steering of the ship, and, what may be of infinitely more importance, will prevent the necessity of continually changing the ropes in consequence of their so quickly wearing out; which is in bad weather frequently very hazardous. In a ship of from four to five hundred tons, the fore and aft motion of the wheel, as proposed by this plan, will not require to be more than two inches backwards and forwards, consequently the whole length of the screw part of the spindle need not to be more than six inches.

The second inconvenience alluded to above is, that the sweep being done away with, instead of the tillar ropes leading round the circumference of a circle, they now, when the tillar is amidships, form the chord of an arc of 35° on each side as shown by *ab*, *bc*, Fig. 93, which is a horizontal view of the leading block on the deck at the ship's side, and of the block at the end of the tillar, for a whip purchase; *db* representing the

middle line of the tillar when amidships, and *d a* and *d c* its middle line when hard over, or when at an angle of 35° on each side respectively, of the middle line of the ship. When the tillar is moved from amidships to hard over on either side, the tillar rope, instead of the two chords *a b*, *b c* of arcs of 35° will become the chord *a c* of an arc of 70°, which, in a ship of from four to five hundred tons, will be found to be at least six inches less than the sum of the two chords *a b* and *b c*, thereby not only causing so much slack rope trailing on the deck, but also, should there be occasion to put the helm hard over, when the ship is scudding, with a heavy sea running, endangering the loss of the rudder; as the back of the rudder is then liable to be struck by a following sea, when, for want of the support of the lee ropes, it may be forced against the bearding, and the pintle carried away. A plan was adopted in his Majesty's navy some years since to avoid this inconvenience (though, strange to say, it does not appear yet to have found its way into the merchant service): it is, to make the barrel of the wheel resemble two cones, with the apex of each in the centre of the length of the barrel, as shown in Fig. 91; then, the ropes being passed round the barrels in the usual way, the helm put amidships, and the ropes hauled taught, on putting the helm over either way, as the barrel revolves, the rope is let off from the smaller part, and is taken up by the larger part, which is about one inch more in diameter than the smaller. Thus the slack rope is taken up, and all parts preserve nearly an uniform tension. If grooves are also made round the barrel, as is frequently done, in the spiral direction which the wheel rope takes, of about a quarter of an inch in depth, the friction of the turns of the rope against each other will be very greatly diminished.

Although the economy of the steering apparatus of a ship is strictly dependent on mathematical principles, erroneous opinions respecting it are frequently advanced, which show that the theory does not appear to be generally well understood. It is not unusual to hear of the propriety of lengthening a tillar, in order to add to the purchase (as it is called) of steering, although the ship is steered with a wheel! But where a wheel is used, it becomes the lever, and the power is applied to it,

and no additional power can be added except by increasing the diameter of the wheel at the spokes: that is, if we wish to retain the old and universal custom; that the helm being amidships, two turns of the wheel will bring it to an angle of 35°, or hard over either way. For, as the velocity of the power is to the velocity of the weight, so is the weight to the power; the lengthening of the tillar must be followed by a corresponding increase of the barrel, or else of necessity the old rule will be done away with.

It is of importance to all seamen, that the whole of the steering apparatus of a ship should not only be in the most perfect order, and on the most simple and correct principles, but that its arrangement should be familiar to them, and it may probably be not the least part of the advantages of the plan which is proposed in the first part of this paper, that the object to be accomplished is attained without in the least interfering with the rules and arrangements which experience has caused to be adopted on board all ships, and which long habit has rendered all seamen acquainted with; some of them are as follow:—

1st. The ropes are passed round the wheel with the sun.

2nd. Five turns are taken on the upper, and four on the lower part of the barrel.

3d. Two turns of the wheel carry the tillar hard over either way to 35 degrees.

4th. The midship spoke is marked, and the staple, or hook, in the barrel is in a line with the midship spoke. The larboard rope works forward and the starboard one aft, as the wheel revolves; thus, a ship being on the larboard tack, and the helmsman ordered to put the helm hard up, heaves the wheel round two turns with the sun, and the helm is hard a-weather.

To make any alterations therefore in the above rules would, in some cases, be attended with danger, especially in a new ship's company, when the men have not well learned their new lessons, which may very likely be the case at a critical moment, when there would be no time for discussing blunders, and by which the ship may be lost.

Art. XXIII.—*Observations on the Materials used in the Fastenings of Ships. By* Mr. Francis Laire, of his Majesty's Dock-yard at Chatham.

There are few scientific subjects which present so many objects of interesting and useful inquiry as Naval Architecture. The forms of ships best adapted to answer the different purposes for which they are designed, the materials of which they are built, and the best methods of combining those materials, all require from their importance the most careful investigation. What can be of more consequence, either personally or nationally, than the security of that machine in which a man ventures his life, and a nation its honour?

It would be an inquiry of considerable interest, to ascertain the practice of ship-building by the ancients; but it is to be regretted how little has been handed down to us on the subject. The magnitude of the ships of ancient Greece and Rome is but little more than conjecture, exaggerated by some and depreciated by others; of their forms still less is known than of their magnitude; and of the methods of putting them together, and of their fastening, there are scarcely any records remaining. It is stated by Vegetius, that brass was substituted for iron in his time; and by Athenæus, that such was the practice as far back as Nero. A galley, supposed to have belonged to Trajan, said to have been buried 1300 years in the lake Riccio, was discovered, which had a sheathing of lead on her bottom, fastened with copper nails; this vessel had also been caulked and doubled. These slight accounts afford the most important part of our knowledge of the connexion of an ancient vessel.

It is not, however, now proposed to enter into the more general question of the mode of fastening ships, but rather of the *materials* which have been used to preserve the connexion when the parts are brought together.

Of the early modes of fastening, it is probable that ligatures were the first used for this purpose, as is seen even at the present day: boats of considerable dimensions, in the East Indies, being fastened by coir (the cordage made from the outside husk of the cocoa-nut), and the intestines of animals

in some uncivilized countries, being made to answer the same end. Wooden pegs were probably the next step, after that iron, and lastly brass and copper.

Our modern fastenings are generally bolts, nails, and treenails: and these again consist, the bolts of iron and copper; the nails of iron, mixed metal, and copper; and treenails of various sorts of timber, cut into a cylindrical shape.

The excellency of a material for ship fastening appears to consist in its being strong, durable, not having a tendency to decay those parts of the timber which come in contact with it, and in its being cheap.

The material which has hitherto been found to answer these conditions best is copper. Iron began to be discontinued in the bottoms of ships in this country[1] about 1783; at which time copper sheathing began to be generally used in our navy. It was found that the iron fastenings in the neighbourhood of the copper were so rapidly oxidized, that copper fastenings were of necessity put into the bottoms of ships to ensure their safety.

The advantages of copper are, that it is strong, although not so much so as iron. It is durable, only a very small portion of its weight being lost after very long service; and it also possesses the third property we have mentioned to a great extent: for although the wood is deteriorated in its neighbourhood, yet it is so trifling in degree, as not to make it a material objection. It however wants the fourth property, it is of great cost; and when it is considered that the weight of copper put into a 74-gun ship, under present circumstances, amounts to about 35 tons, at a value of about 3000*l*., it must be seen that the expense would be enormous, if it were used to the exclusion of the more general fastening of treenails and iron. It is evidently, therefore, a great desideratum to find some substitute of less value. Were it not for this, there could be no doubt that a ship fastened wholly with copper bolts, to the exclusion of both iron and wood, would leave nothing more to be desired.

Nails are but little used in modern ship-building in this country, at least in the more important parts of fastening. The

[1] See Knowles on the Preservation of the Navy.

metal nail, from its taper shape, is not to be depended on where there is any strain, since, if it 'give' at all, it evidently becomes loose immediately. The iron nail, while it retains its strength, is a much more effectual fastening, since the corrosion, which almost immediately takes place, sets it so firmly that there is little danger of its starting. This corrosion, however, in a few years reduces its strength to almost nothing; and if exposed to the action of sea water, it may be expected to be reduced to a mass of oxide long before the timber is decayed. Notwithstanding this, nails of an immense size and length are used by the Spaniards and Portuguese, and in the East Indies, as the general fastening of their ships' bottoms: being driven through the bottom, and four or five inches of the point turned on the inside, making indeed an effectual clinch, but having an exceedingly clumsy and unworkmanlike appearance.

With regard to mixed metal as a fastening, little need be said: it is too brittle to allow of its being clinched; and without this security, there is not much confidence to be placed in bolts either wholly or partly composed of copper. It is now but little used, except as nails in the weather decks. The dumps or bolt-nails into which it has been also cast, are seldom used to any great extent, except in fir, where treenails are considered of too great diameter in relation to the scantling of the timbers, and are also found to be very injurious to the wood.

We now come to that important instrument the treenail.[1] Of this the opinions that have been expressed are so opposite, that they are for that reason both likely to be far from the truth; one party affirming it to be the "worst fastening that could possibly have been devised," and the other extolling it as the best possible fastening. We shall take a middle course: its utility is proved by its universal application; its inadequacy is apparent from the necessity there exists of using metallic fastening in its aid. Perhaps we cannot do better than try it by the properties we have deemed essential in ship fastening. And first, as to strength: here its deficiency is manifest, for although made of a diameter as large as can be prudently used,

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[1] They are supposed to be coeval with our navy, mention being made of them as early as 1560.—Knowles on the Preservation of the Navy.

without wounding too much the plank and timbers, it is found quite unable to resist the strain of the caulking-iron without the due support of metallic fastening, it having been constantly found, that where a ship has been much caulked the treenails were upset or broken, where metallic fastening has been either altogether omitted or too sparingly employed. As to durability, it is to be apprehended that a shorter period must be assigned to treenails than they have even hitherto attained. This duration must of course depend in some measure on the quality of the timber of which they are made; but there is yet another condition generally admitted to be essential to the duration of timber; that those parts which are brought into close contact should be as nearly as possible composed of the same substances, otherwise the chemical process of decomposition may be greatly accelerated. This is remarkably apparent in the decomposition caused by the contact of oak timber with teak. On this account the contact of pieces of different species of wood is to be avoided as much as possible. At the present day, when, from the scarcity of English oak, woods of various kinds are resorted to as substitutes for that valuable material, of whatever kind the treenail may be, it is impossible to comply with this condition, since, if it pass through a plank of English oak, it is probable the remainder is driven into a timber of A rican oak, &c. On the other hand, an English oak timber is covered by a plank of English or Dantzic oak, fir, elm, beech African, &c. Still as a sufficient quantity of English timbers and plank is not to be procured, we must hope that the extraordinary precautions of seasoning, ventilating, roofing, and other salutary measures, will counteract the ill effects which might otherwise reasonably be expected to ensue.

With regard to the treenail, as a mere fastening, experience justifies a high opinion while it remains sound. Its shape enables every part of it to hold firmly, while its elasticity allows it to be driven with a drift, which ensures a contact almost perfect, and which the swelling of the treenail, from the moisture it imbibes after it is in the water, makes still more certain; so that it is much more common to see a well-driven treenail leak through its substance, than between it and the timber. As a further proof of the goodness of this fastening, while

sound, we appeal to the professional man, who must have frequently remarked the trouble which a single treenail will sometimes occasion in the breaking up of a ship; resisting by its tenacity and toughness the efforts of the workman to clear it, and only yielding at last to his saw. But the same plank will also furnish examples of treenails of scarcely greater strength than so much pottery, and of others so decomposed that a shell in the hole is all that is left, the remainder being completely decayed.

The third condition, that fastening shall not decay the timber around it, has been in some measure noticed in what has been said of the durability of treenails. It may be necessary however, to state more distinctly that the plank in the neighbourhood of treenails is sometimes in nearly as bad a state as that round iron; with this difference, that the decay takes place on the outside of the plank in the latter case, and on the inside in the former. This fact may be thus accounted for: the head of the bolt is naturally first acted on by the water or atmosphere, and a mass of oxide is quickly formed there, which produces its pernicious effect on the outside of the planking. The treenails on the contrary absorb the moisture from the head, a part of it is naturally deposited in the joint between the timber and plank, and decay on the inside is the consequence.[1] But here it may be remarked, that nothing can be more varied than the result of observations on the decay of timber: in one case the treenail is entirely rotten while the timber is perfectly sound around it; in another part the treenail is as fresh as when put in, and the timber may be picked out with the fingers. Indeed the results of our experience on timber altogether are most unsatisfactory, the fact of to-day contradicting the observations of the past year, and that of to-morrow the theory of half a century's formation. There is no chance of its being otherwise till experiments are made in a systematic manner, conducted with care, and recorded with exactness, but above all registered and remembered; so that the result may not be lost or for-

[1] This was very remarkable in the *Terpsichore*, of 32 guns, lately broken up at Chatham, where there were holes round the treenails on the inside of the plank of the bottom, 1½ inch within the other parts of the surface.

gotten. Till this shall be the practice, experienee will be but a mass of isolated facts, without combination or benefit; and serve but too often to prop an erroneous theory, or foster a pre-conceived opinion.

The treenail possesses our fourth qualification in an eminent degree: it is the cheapest fastening we can apply, and therefore it will require some modification of other materials before it is likely to be superseded. Treenails of African timber have lately been introduced, but not with complete success; although perhaps the best substitute for English oak treenails hitherto used. It is not a wood that can be cleft; they are therefore sawn, and then mooted; consequently, from the nature of the wood, the treenail frequently breaks off in driving, although, when the grain is straight, it drives like a bolt. There is a material objection, however, to any of these hard woods for the manufacture of treenails; that unless they are driven very tight, they are likely to leak; and if they are driven tight enough to prevent that, they endanger splitting the planks into which they are driven, from the want of elasticity.

Iron bolts, as a security for the outside planking, are now used only on the topsides, at some distance above the load-water line. Its strength is considerably greater than that of copper, while it is specifically lighter. It is also very cheap, for these two reasons, therefore, it is extensively used for fastening above the water.

The great drawbacks on the use of iron are its want of durability from corrosion, and the great effect it has in destroying the timber around it. The corrosion is such, that in eight or ten years it is no longer to be depended on; and in some cases, where it has been used on the bottoms of ships which have been long in existence, planks have actually fallen off, when the vessel has been taken into a dock.

There have been many methods proposed of rendering the iron fastenings more durable: viz., by casing or washing them with tin or copper, but as yet it would appear, from none of of them having been adopted, with but indifferent success. The causes of failure seem not to have been sufficiently recorded, for we know little of these experiments except that they have been made.

There is now, however, a very important experiment going forward for this purpose. The plan is under the direction of Capt. Sweny, R. N.; but we believe the discovery or invention is due to Dr. Rivere, an intelligent American, who after an immense number of experiments, arrived at the following mode of application. The protecting metal is a mixture[1] of zinc and copper, cast into rings or plates; the bolts being driven as usual, but having a ring of this metal at the head and point. After the bolt is driven, a piece of the protecting plate is let in over the bolt-head, which is carefully cleaned, and the plate then well dressed on the bolt, to ensure a complete contact. The only condition prescribed with regard to this metal is that the surface of this protecting metal shall not be less than 5 per cent. of the surface of the bolt to be protected. From the specimens, exhibited by this gentleman, of bolts which have been immersed in brine, salt-water, &c., and which, after a trial of a year and a half, are still perfectly bright, there is good reason to hope for some success from this mode of treatment.

It is curious that while this experiment was being carried into effect in Chatham dock-yard, another of a something similar nature was discovered in the Terpsichore of 32 guns, whilst breaking up. This was of several iron nails which were used to fasten a part of the upper deck, between the fore and main hatchways: this part of the deck was of teak, and had been put into the ship when repaired in India about 25 years before. These nails were tinned, and almost all that were found, were in a very perfect state, both that part which had been in the teak deck, and that part in the oak beam. Compared with the nails in a plank under similar circumstances, by the side of them, which had not been so protected by tinning, they were in a decidedly better state: but as the latter also were not so much corroded as might have been expected from their long service, in consequence of the dry state of the deck, the ship having been a receiving hulk for the last 20 years, the experiment, though certainly favourable, and bringing to the mind of the

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[1] The specific gravity of this mixed metal is only 6950, while that of copper is 8788, and zinc 7191.

writer a conviction of its utility, is yet, from not having been made on the bottom of a ship, not of that decided character that could have been wished on so important a subject. It may be remarked here, however, in connexion with this experiment, that the pins in the shackles of chain cables, to facilitate the taking the cables into short lengths, have for some few years past been tinned; and from the testimony of some intelligent officers on board ship, as well as of the blacksmiths employed in surveying these chain cables when brought to the dock-yard, it has been found decidedly useful, inasmuch as they were quite free from corrosion, except where the head had been battered in driving, and the tin beaten away.

This experiment is of so important a character, that its success or failure involves a remarkable era in ship-building. The expense of copper has been found so great, that the utmost care and economy in its expenditure have been prescribed in the royal dock-yards; should, however, these experiments succeed, we shall have a metal fastening possessing every property that can be desired; combining strength with cheapness, and durability in itself, with that of the material in its neighbourhood.

In order to supply, in some degree, the want of an experiment on the tinning of iron bolts on the bottom of a ship, a piece of green oak was procured, and some bolts, previously tinned, about a foot long, and an inch in diameter, were driven into it. One of these was driven out again to ascertain if the tin had been rubbed off by the friction in driving it. It was found as perfect as at first.

The piece of wood was then coppered, and placed in the water of the Medway, where it is intended to remain a sufficient period to put this question at rest.

It has been objected to tinning, that in driving or clinching a bolt, the tin would undoubtedly be removed from the head and point. This is very probable, but as the rings would also be tinned, all the parts in contact with the wood would be protected, and the only effect would be a little reduction of the head and clinch.

It should have been mentioned that the protecting metal of Capt. Sweny, or some modification of it, is also formed into

sheets for sheathing ships' bottoms; with which several ships in the merchant and India service have been sheathed. It is to be hoped that the owners or some one connected with those ships, will publish an account of the result of this experiment, as from the cheapness of the metal it would be a most desirable substitute for that expensive article, copper. We confess ourselves not sanguine on this point, on account of the oxidation of the copper, being that quality which preserves the bottom free from those animal and vegetable substances which are found to adhere where copper is not used. And this we think also will cause the failure of all those measures, such as painting, zinc plates, iron protectors, &c., which have for their object the preservation of copper sheathing; by destroying one of the principles on which its utility is founded. This was conspicuously the case with the protectors recommended by Sir H. Davy.

There is another mode of fastening, which, though it may be said to have had its day, yet deserves to be mentioned; this is by nuts and screws. There have been various suggestions in order to make this powerful instrument available in ship-building; but as far as we have yet seen, they have almost entirely failed.

It has been the frequent endeavour of many ingenious men, to place them so that when any shrinkage takes place, the screw may be employed to bring the parts again into contact, and by means of the nut keep them together. When, however, it is recollected, that for this to take place, every bolt must be exactly in the same direction, and that every bolt must be set nearly simultaneously, it will be seen that there is more difficulty than would at first be apprehended; and when to this is added the shrinkage of the materials on and around the bolt, the chances that in the working of the vessel it may have been, though ever so slightly, bent, it is hardly too much to say, that it is impossible to answer the sanguine expectations that have been held out in their favour.

There is another objection to the employment of screw fastening, that the security derived from the nut on the end is much inferior to that of the common clinch.

This would not at first be expected, but was found to be the case in an experiment, in which two bolts of the same diameter, one

with a screw at the end and set up with a nut; and one clinched on a plate in the common way, were subjected to the same strain. It was expected that the threads, four or five of which were taken by the nut, would be of greater strength than the mere clinch, in the proportion of the quantities of metal apparently effective. The result, however, was different: two or three trials proved the value of the clinch, since the screw bolt broke in the thread, while the clinched bolt remained undisturbed. The trial was thus made: A heavy hawser being rove through the two ring bolts experimented on, tackles of sufficient power were then bent to this hawser, and by a leading block the angle equally divided. Horses were then put to the fall, and driven till one or the other broke.

This result we imagine to have taken place in consequence of the injury sustained by the fibre of the iron in cutting the screw: on the same principle as a spar will be sprung, where a slight score has been made round it, with much less force than from its diameter would appear to be adequate. On the other hand, the use of the hammer had so tempered the iron of the clinch as to render it capable of a greater resistance than its thickness would lead us to expect.

We have as yet made no mention of an improvement in ship-fastening, which should hardly have been so long passed over in silence, considering its value and importance. We allude to the dowell or circular coak. The coak or dowell has long been used in masonry, but for its introduction into ship-carpentry we are indebted to General Bentham, about 1802 or 1803.[1] Its present extended employment, however, is due to Sir Robert Seppings, who has availed himself of its valuable properties wherever it can be usefully applied; and its situation above and below the buts, in the thick strakes of the planking, in the scarphs of the shelf, &c., must have a powerful effect in preventing longitudinal extension. Its great value, however, is in its preventing the possibility of bad workmanship, to which the operation of tabling, which it has superseded, was peculiarly liable. To those who are not conversant with these details, it may not be superfluous to explain that a dowell is a

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[1] Knowles, on the Preservation of the Navy.

cylindrical piece of wood or other material (now frequently iron, hollow, and filled with cement), of a certain diameter according to the magnitude of the timbers to be connected. The dowell engine may be considered as a large centre-bit fixed in a brass frame, of the same diameter exactly as the dowell to be used, and having a small spindle in its centre. The timbers to be dowelled having been brought into contact (fayed), a small auger, the size of the spindle, is put through at the places where the dowells are to be placed. The timbers are then separated, and the spindle of the dowell-engine inserted in the auger hole; the mortice of the dowell is then made in each piece, and necessarily, by means of the spindle, exactly in the proper direction; and from the dowells and the engine being of precisely the same diameter, a perfect fitting is ensured. It should be observed, that whatever number of coaks there may be in the seating (fitting surface), they must be precisely in the same direction, otherwise, it is evident, the surfaces could not possibly be brought together.

In taking leave of this subject, it is impossible for a shipwright not to feel impressed with its importance. In the first place, fastening, if not properly applied, is worse than useless, it is weakening that which it is intended to strengthen, and throwing away the time and labour of the workman and the cost of the materials. Again, fastening, although properly placed, if not well-driven, is useless and deceitful: compromising the safety of the ship and the lives of the crew.

Art. XXIV.—*Communication from* Commander Marshall *on his Improved Gun-Carriages.*

(*To the Editors of Papers on Naval Architecture.*)

Gentlemen,

Having seen your notice of my work on improved gun-carriages in the last number of 'Papers on Naval Architecture,' I forward you the following account of some improvements I have since made in them, for insertion in your next number.

From the experience obtained from a continued course of experiments made during the past summer at the Nore, under the superintendence of that highly-distinguished officer, Sir Jahleel Brenton, and myself, I have been enabled to remove one or two trifling objections, and to make further improvements in them. The principal ones are: 1st. A method of working the gun upon the port-sill without a crutch or breast-carriage, should it be disabled, and no supply of spare ones on board; and, 2ndly. A better mode of securing the lower deck guns.

A piece of wood about 4 inches square is bolted to the inner part of the upper surface of the port-sill; the muzzle of the gun when depressed to its greatest extent, recoiling clear of it, by the same cause which admits of the muzzle coming in when depressed below the outer edge of the portsill. This fixture keeps out wet and fire from the guns; and on the lower deck may be made to answer the purpose of the port-bars: it will, in fact, have the effect in keeping out water when the ship heels, as if the ports were so much higher out of the water. By taking away the breast-carriage, the gun is found to work with great facility on this piece of quarter, trains to an angle of 45°, and elevates and depresses much more than on the old carriage. Thus, though every facility is afforded of replacing a disabled breast-carriage, an action may be effectively continued without it.

Four 32 pounders having been subsequently fitted on the lower deck of the *Donegal*, it was the most convenient method to secure them, by lifting the muzzle out of the crutch (a very simple and quick operation), and lowering it down till it rests upon a block, level with the water-way. This method is due to the suggestion of Sir Jahleel Brenton, for whose attentive consideration to my proposed improvements in gun-carriages I feel much indebted. In this position the whole weight of the guns is about 1 foot 6 inches lower in the ship than when mounted on the old carriages. The muzzle of the gun in this case bears against the ship's side when rolling, at a much stronger part than that over the port to which the muzzle is lashed on the old plan. Should any of the guns ever break adrift from this position, their muzzles being laid on the deck, the safety of the ship is not endangered, as by the old method; the whole gun

when secured, lying in a position below the port-sills. The circulation of air for ventilation, and the accommodation for the hammocks of the crew, are also nearly as complete as if no guns were on board.

During all the experiments of continued cannonading with double shot, the recoil of the 32-pounders on the new carriages was so perfectly steady and easy, that the deck was never in the least shaken by it. This is important in the event of guns of heavier metal being required for the upper decks of ships. The long 32-pounders when put on the upper deck of the *Barham*, were found to kick so violently as to endanger the decks and beams, and it consequently became necessary to have another description of 32-pounders cast, to equip that ship. Now as the old 32-pounders, mounted on the new carriages, are as steady as it is possible for any guns to be, a ship may be equipped with long 32-pounders on all the gun-decks, as far as relates to the strength of the decks. By securing the guns in the low position just mentioned, the disadvantageous effect of the increased weight of heavy metal on the upper decks of ships, in affecting their stability, is also much diminished. From the decrease in the number of men required to work the guns on the new carriages, heavy metal may be ably worked by the crew.

I remain, Gentlemen,

Your obedient servant,

JAMES MARSHALL.

H. M. S., Donegal, Nov. 27th, 1830.

ART. XXV.—*A Popular Explanation of the Theory of the Tides.* By P. MASON, Esq., A. M., First Mathematical Assistant at the Royal Naval College, Portsmouth.

THE following account of the theory of the tides does not profess to differ in any manner from that which is generally received; the only object of this paper being to explain that theory in a popular manner. The investigation supposes the earth, independently of the action of the sun and moon, to be a fluid mass at rest, and acted upon by no force but the attraction

of its particles, and which must consequently be in the form of a sphere. It is evident that this theory cannot agree with the actual figure that the sea assumes, the whole globe not being a fluid, nor the whole surface even covered with water; but the *tendency* of the forces is the same as if the whole were fluid, and this is all that we propose to consider.

Let CAD (Fig. 94) represent the section of a fluid sphere made by a plane coincident with the plane of the paper, T the centre, S a remote body in the plane $CADB$, and which attracts the particles of matter of the globe by forces which are greater in the same proportion as the squares of the distances from S are less, it is proposed to explain in an easy and popular manner the nature of the effects produced by the force S, upon the figure of the globe whose particles attract each other by forces also inversely as the squares of their distances.

Take any point P in the globe, join ST and SP; let ST represent the force exerted by S on T, which therefore represents the whole effect of S to urge the globe in the direction TS. The force of S on P is manifestly greater than the force on T, and therefore a line longer than ST must be taken to represent this greater force. Let SP be produced to L so that $SL : ST ::$ force of S on P : force of S on T, or as $ST^2 : SP^2$; then LS represents the attracting force of S on P, which is in the direction PS.

This force LS on P may be considered the resultant, or compound of two forces acting on P, one parallel to TS, and the other to PT.

Draw LN parallel to TS, and LM parallel to PT, complete the parallelogram $LNSM$. Then LN and LM are the two forces whose compound force or resultant is LS. We may therefore suppose the particle P as acted upon by the forces LN and LM; of which LN tends to draw P in the direction PR parallel to TS, and LM to press it towards T.

Now S acts on T by the force TS, and tends to draw T in the direction TS by this force. The points P and T are therefore drawn in parallel directions by the forces LN (which is equal to MS) and TS respectively. If these forces were equal they would not disturb the relative positions of P and T; but they are unequal, their difference being equal to MT; hence

the relative positions of P and T will be disturbed by the forces MS on T, and TS on S, exactly as much as if no force whatever in the direction TS acted on T, but a force equal to MT alone acted on P in the direction PR parallel to TS. The force parallel to TS, therefore, which disturbs the position of P with respect to T is the force MT. Therefore draw PR parallel to TS, and make it equal to MT, then PR is the force on P parallel to TS which disturbs the point P with respect to T. Besides this force, that parallel to PT on the force LM tends to press P towards T. The particle P, therefore, is disturbed in its position with respect to T by the forces PR and LM.

It is further manifest that PR or MT will be greater or less according as the difference of the distances of P and T from S is greater or less; particles at and near to C and D being nearly at the same distance from S as T is, will be drawn by S in a direction parallel to TS, by nearly the same force as T is drawn in that direction, or MT, for particles near to C and D, is very small: while the like force on particles near to A will be the greatest possible, the difference of the attraction of S on A and T being the greatest.

To consider the effect of S to disturb the hemisphere CBD (Fig. 95), take a point P in the hemisphere CBD, join PS. Then since SP is greater than ST, the force of S on P is less than the force of S on T. Let, therefore, SL represent the force of S on P in the same scale that ST equals the force of S on T. Then $SL : ST :: ST^2 : SP^2$. The force LS may be considered the resultant or compound of two forces acting on P, one parallel to TS, as LN, and the other parallel to PT, as LM.; the parallelogram $LMSN$ being completed.

Hence, instead of the force LS on P, we may consider it as acted upon by the two forces LN or MS, and LM; MS tending to draw P in the direction parallel to TS, and LM to press P towards T.

Also S attracts T in the direction TS by the force TS. Hence P and T are drawn by S in directions parallel to TS by the forces MS and TS respectively, and if these forces were equal, P and T would move in the direction TS

equally, and their relative positions would not be disturbed by the forces parallel to TS, but these forces are unequal, and the difference is TM. T is urged towards SN in the direction TS, by a force greater by TM than that by which P is urged in the same direction. The relative positions of P and T will consequently be disturbed by the forces MS and TS by the difference TM. T being urged in the direction TS by a greater force by this quantity, than P is urged in the direction TS; the effect is therefore the same with respect to the position of P and T as it would be if T were not attracted by S, and P were urged by a force equal to MT in the direction ST. Besides the disturbing force MT, P is urged by the force LM which presses P towards T; through P draw PR parallel to ST and equal to MT. Then the forces which disturb the relative positions of P and T are PR and LM.

Hence the hemisphere CPD will be disturbed in a manner similar to that in which CAD is disturbed. The fluid rises about B above the level of the sphere, as we observed it rise about A above the same level. About C and D, the only disturbing force, is the force LM, which presses P towards T: the fluid consequently about C and D, or all round the globe at the distance of 90° from A and B, sinks below the level of the sphere, and rises above it about A and B. The spherical form is therefore changed to that of a prolate spheroid, as represented by the Fig. 96.

We shall now proceed to calculate the quantities of the disturbing forces PR or MT, and LM.

Let s represent the attraction of S (Fig. 97), on a particle of matter at the distance which we consider the unit.

Then $\frac{s}{ST^2}$ = force of S on T, and $\frac{s}{SP^2}$ = force of S on P.

Let $ST = D$, $PT = d$, and the angle $STP = x$.

Then $SP^2 = ST^2 + PT^2 - 2\,ST\,.\,PT\,.\cos.\,x$, (by Euclid, Prop. XIII. Book 2,) which is equal to

$$D^2 + d^2 - 2\,D.\,d\,.\cos.\,x.$$

Therefore, the force of S on $P = \frac{s}{D^2 + d^2 - 2D.d.\cos.x}$, which is in the direction PS, and which is the force represented by LS.

Hence $\frac{s}{D^2 + d^2 - 2D.d.\cos.x}$: force MS :: LS : MS :: PS : PT (by similar triangles SLM and SPT) that is as $\sqrt{D^2 + d^2 - 2D.d.\cos.x}$: D.

Therefore the force on P in the direction TS or the force MS will equal $\frac{s.d}{(D^2 + d^2 - 2D.d.\cos.x)^{\frac{3}{2}}}$; and the force of S on $T = \frac{s}{D^2}$, hence the disturbing force MT which equals $MS - TS$ is equal $\frac{s.D}{(D^2 + d^2 - 2D.d.\cos.x)^{\frac{3}{2}}} - \frac{s}{D^2}$

$$= \frac{s.D}{D^3\left(1 - \frac{2D.d.\cos.x - d^2}{D^2}\right)^{\frac{3}{2}}} - \frac{s}{D^2}$$

$$= \frac{s}{D^2}\left(1 - \frac{2D.d.\cos.x - d^2}{D^2}\right)^{-\frac{3}{2}} - \frac{s}{D^2}$$

Now in the case we are considering, D or ST is very great when compared with d, consequently $\frac{2D.d.\cos.x - d^2}{D^2}$ is nearly the same as $\frac{2D.d.\cos.x}{D^2}$ or $\frac{2d.\cos.x}{D}$; therefore the force PR or MT

$$= \frac{s}{D^2}.\left(1 - \frac{2d.\cos.x}{D}\right)^{-\frac{3}{2}} - \frac{s}{D^2}$$

$$= \frac{s}{D^2}.\left(1 + \frac{3}{2}.\frac{2d.\cos.x}{D}\right) - \frac{s}{D^2}$$ very nearly, by the binomial theorem; the powers of $\frac{d}{D}$ above the first being neglected in the expansion, as being very small.

Hence the difference of the forces, which is represented by

$$PR = \frac{3d.\cos.x.s}{D^3} \qquad (1)$$

Let RP be produced to meet CT in K, then $PK = d.\cos.x$, hence $PR = \frac{3PK.s}{D^3} = 3\frac{s}{ST^3}.PK$.

Again, to find the force represented by LM we have $\frac{s}{SP^2}$ or force LS : force LM :: LS : LM :: PS : PT.

Therefore the force represented by $LM = \frac{s.PT}{SP^3} =$

$$\frac{s.PT}{(D^2 + d^2 - 2D.d.\cos.x)^{\frac{3}{2}}} =$$

$$\frac{s.d}{D^3}\left(1 - \frac{2D.d.\cos.x - d^2}{D^2}\right)^{-\frac{3}{2}}$$

$$= \frac{s.d}{D^3}\left(1 - \frac{2d.\cos.x}{D}\right)^{-\frac{3}{2}}$$

$$= \frac{s.d}{D^3}\left(1 + \frac{3d.\cos.x}{D}\right) \text{ nearly, as before} =$$

$\frac{s.d}{D^3}$ nearly; the other quantity $\frac{3d^2.\cos.x}{D^4}$ being very small compared with $\frac{s.d}{D^3}$ - - - - - (2)

Hence the force represented by $LM = \frac{s.PT}{ST^3}$ and is therefore the same for all particles on the surface of the sphere.

The force represented by PR or $\frac{3s.d.\cos.x}{ST^3}$ may be resolved into two others PE in the direction TP, and ER perpendicular to TP. Of these forces PE tends to draw P from T in the direction TP, and ER neither to draw it from T nor to press it nearer to it, but to cause it to glide along the surface at P.

The force of PR in the direction PE : PR :: PE : PR :: PK : PT by similar triangles, therefore the force of PR in the direction PE : $\frac{3s.d.\cos.x}{D^3}$ :: PK : PT :: $\cos.x$: 1.

Therefore the force of PR in the direction $PE = \frac{3\,s\,.\,d\,.\,\cos.^2 x}{D^3}$ - - - - - - (3)

In like manner the force of PR which is in the direction ER is equal to $\frac{3\,.\,s\,.\,d\,.\,\cos.\,x\,.\,\sin.\,x}{D^3}$ - - (4)

We have then, upon the whole, the disturbing forces on P;

1st. The force in equation (2) $= \frac{s\,.\,d}{D^3}$ in the direction PT.

2nd. The force in equation (3) $= \frac{3\,.\,s\,.\,d\,.\,\cos.^2 x}{D^3}$ in the direction TP.

3rd. The force in equation (4) $= \frac{3\,.\,s\,.\,d\,.\,\cos.\,x\,.\,\sin.\,x}{D^3}$ in the direction of a tangent at P.

The forces in equations 2 and 3 affect the gravitation of P to T, one adding to P's gravitation to T and the other taking from it. The whole disturbing force affecting P's gravitation is

$$\frac{3\,.\,s\,.\,d\,.\,\cos.^2 x}{D^3} - \frac{s\,.\,d}{D^3} = \frac{s\,.\,d}{D^3}(3\cos.^2 x - 1.)$$

The gravitation of P to T is therefore diminished for every value of x, which makes $\frac{s\,.\,d}{D^3}(3\cos.^2 x - 1)$ a positive quantity; or for every value of x; which makes $3\cos.^2 x$ greater than 1.

Now $3\cos.^2 x - 1 = 0$, when $\cos.\,x = \frac{1}{\sqrt{3}}$, or $x = 54°\ 44'$ nearly. If x be less than $54°\ 44'$, the gravitation of P to T is diminished. If x be greater than $54°\ 44'$, then $\frac{s\,.\,d}{D^3}(3\cos.^2 .\, x - 1)$ is negative, or the gravitation of P to T is increased.

The same applies exactly to the other hemisphere. Hence all round A and B, to the distance of $54°\ 44'$ from A and B, the force of gravity is diminished by the attraction of the distant body S, through the portions between A and B, (Fig. 98) and the sections $a\,c\,d$ and $b\,f\,e$ made by planes perpendicular to AB, the arcs $A\,a$ and $B\,b$ being $54°\ 44'$; and

between these parallel circles the force of gravity is increased by the disturbing force of *S*. Hence the fluid mass rises at *A* and *B*, and through the portions *A a c d* and *B b f e*, above the level of the sphere; and sinks below the same level at *C* and *D*, and between the circles *a c d* and *b f e*.

This reasoning may be extended to the figure which the sea has a tendency to assume in consequence of the action of the sun. It is manifest that the effect of the sun is to cause the water to rise immediately under the sun as at *A*; and at the point *B* at the opposite side of the earth to *A*; and to depress the water all round the earth at points 90° from the sun, and to the distance of 35° 16′ on each side of this line.

The same reasoning may also be applied to the moon's action upon the earth; the moon being at a distance very great when compared with the radius of the earth. The effect therefore of the moon to alter the figure of the sea is similar to that of the sun; it tends to cause the water to rise immediately under the moon, and at the opposite point on the earth, to a distance of 54° 44′ round these points, and to depress the water in the spaces between these parallels.

From this it is manifest that the sun and moon being in conjunction or in opposition tend to raise the tide in the same places, and their effects are added together. But when they are in quadratures, they act in opposition to each other; the moon elevating the water which the sun depresses, and the sun elevating that which the moon depresses.

We shall in another number show that the figure which the sun tends to communicate to the earth by its disturbing force is a prolate spheroid, and the moon tends also to cause a spheroidal figure; and their united effect tends to cause also a spheroidal figure, the vertices being between the lines drawn through the centre of the earth to the sun and moon, and these lines produced backwards and always nearer to the moon than to the sun. The moon having an easterly proper motion of about 13° from the sun in a day, the vertex of the tide moves in the same direction, and consequently comes to the meridian later every successive tide.

The vertices of the tide lie in a line tending to a point between the sun and moon, which are not many degrees from the equa-

tor: hence as the earth revolves round its axis, an observer in the twenty-four hours will be carried by the earth's rotation through both the tides; and thus it is that there are two tides in the day.

Art. XXVI.—*Proposal for altering the Armament and Construction of Ships of the Line.* By Captain Napier, R.N., C.B.

A very considerable inconvenience arises in line-of-battle ships from the necessity of having a part of the ship's company to live and sleep on the fighting decks. In our present line-of-battle ships it would be very difficult to blockade the ports of an enemy as enterprising and as well disciplined as ourselves; as it would be impossible to keep the ship clear for action without harassing the men, while the enemy in port could be ready when they pleased, taking their own time to put to sea; and if they did so in dark or thick weather, you might be taken before your hammocks were on deck.

At present a line-of-battle ship is only a frigate with guns between decks, where the ship's company live and sleep; whereas, I conceive, a line-of-battle ship should be a frigate risen upon one deck, but of considerably larger dimensions, with the men berthed below as they are in a frigate. I have made two models, one showing the *Nelson* as she is, carrying 120 guns; the other, the ship I propose, carrying 100 guns, her decks are all lowered, in comparison with those of the *Nelson*, 3 feet; the guns are taken out of the lower deck, and her metal is increased in proportion to the weight of the 20 guns which she loses, together with the weight of the poop and the three feet of top-sides which are taken away. The following is a comparison of the size and force of the two ships:

Nelson.

Length on the lower deck, 205 feet; breadth, 54 feet 6 inches.

	No. of Guns.			Weight of one Gun. Cwt.	Total Weight. Tons	Cwt.
Lower deck	2	68-pdr.	carronades	50	5	0
,,	30	32 ,,	long guns	64	96	0
Middle deck	34	32 ,,	,,	55	93	10
Upper deck	34	32 ,,	,,	48	81	12
Quarter deck & Forecastle.	16	32 ,,	carronades	17	13	12
	4	18 ,,	long guns	42	8	8
Total No. of guns	120			Total weight of guns	298	2

Proposed Line-of-Battle Ship.

Length on the lower deck, 212 feet; breadth, 54 feet 6 inches.

	No. of Guns.		Weight of one Gun. Cwt.	Total Weight. Tons	Cwt.
Lower deck	2	68-pdr. carronades..	50	5	0
,, ...	34	32 ,, long guns ..	64	108	16
Main deck	36	32 ,, ,, ..	64	115	4
Quarter deck & Forecastle...	28	32 ,, ,, ..	55	77	0
Total No. of guns	100		Total weight of guns	306	0

The weight of the broadside of the *Nelson* is 1928 pounds, and of the proposed ship it is 1636. That is, firing single shot, the broadside of the *Nelson* is 292 pounds heavier than that of the ship I propose; but my ship can fire three shot from the lower and main deck guns, and double shot from the forecastle and quarter deck guns; whereas the *Nelson* is confined to three shot from the lower deck guns, double shot from the middle deck, and single shot from the upper deck and quarter deck and forecastle guns: which will give my ship a superiority of 752 pounds in fine weather; and, in a rough sea, when the *Nelson* would be obliged to shut her lower deck ports, she would be blown out of the water by my ship.

The seven feet additional length which the proposed ship would have, would be sufficient for the guns on the lower and main decks; and the quarter deck and forecastle guns should encroach on the gangways. The height from the limber strake to the under side of the orlop beams would be about 13 feet; and after providing for a cable tier, and a spare deck for the people, the lower gun-deck beams would require to be lifted about four feet higher than the *Nelson's*: of course the ports will be raised as much. The stowage which would be lost in the hold, would be compensated for by the additional length.

This ship has the round stern and bow proposed by Mr. Blake: she will measure about 100 tons more than the *Nelson*, throw a heavier broadside, have more stability, carry her ports from 9 to 10 feet above water, keep her guns always run out, and, having her men berthed below, be ready for action at all times; and in blockading an enemy's port at night, need not fear the most enterprising antagonist.

The following is a statement of the reduction of top-hamper in the proposed ship, with two different armaments, in comparison with that of the *Nelson*:—

Proposed Ship with her full Armament.

				Cwt.	Tons	Cwt.	Tons		Feet		Moment.
Lower deck	2	68-pdr.	carronades	at 50 each	5	0	114	by	10	the height	= 1140
,,	34	32 ,,	long guns	,, 64 ,,	108	16					
Main deck	36	32 ,,	,,	,, 64 ,,	115	4	115	,,	17	,,	= 1955
Quarter deck and Forecastle	28	32 ,,	,,	,, 55 ,,	77	0	77	,,	24	,,	= 1848
Total number of guns	100			Total weight of guns	306	0					4943
					Channels and anchors		22	,,	23	,,	= 484
										Total	5427

		Tons		Feet	Moment.
Weight to be deducted	Three feet of topsides	30	by	25	= 750
	Poop	20	,,	34	= 680
				Total moment. to be deducted	= 1430
					3997

Proposed Ship with reduced Armament.

	No.			Cwt.	Tons	Cwt.	Tons		Feet		Moment.
Lower deck	2	68-pdr.	carronades	at 50 each	5	0	114	by	10	the height	= 1140
,,	34	32 ,,	long guns	,, 64 ,,	108	16					
Main deck	36	32 ,,	,,	,, 55 ,,	99	0	99	,,	17	,,	= 1683
Quarter deck and Forecastle	28	32 ,,	,,	,, 48 ,,	67	4	67	,,	24	,,	= 1608
Total number of guns	100			Total weight of guns	280	0					4431
				Channels and anchors			22	,,	22	,,	= 484
										Total	4915
										Deduct for Poop, &c.	1430
											3485

Nelson.

	No.			Cwt.	Tons	Cwt.	Tons		Feet		Moment.
Lower deck	2	68-pdr.	carronades	at 50 each	5	0	101	by	6	the height	= 606
,,	30	32 ,,	long guns	,, 64 ,,	96	0					
Middle deck	34	32 ,,	,,	,, 55 ,,	93	10	93	,,	13	,,	= 1215
Upper deck	34	32 ,,	,,	,, 48 ,,	81	12	82	,,	20	,,	= 1640
Quarter deck and Forecastle	16	32 ,,	carronades	,, 17 ,,	13	12	22	,,	27	,,	= 594
	4	18 ,,	long guns	,, 42 ,,	8	8					
Total number of guns	120			Total weight of guns	298	2					4055
				Channels and anchors			22	,,	25	,,	= 550
											4605

The moment of the weights of the proposed ship above the water compared with that of the *Nelson*, will be thus decreased, with the full armament, 608 tons, and with her reduced armament, 1120 tons, by which the centre of gravity will be proportionably lowered, and consequently the stability increased, independently of other circumstances in the proposed alteration which would also increase the stability.

The construction of large frigates to carry 50 32-pounders will render useless 50-gun ships on two decks, 64's and small 74's, and they will be far more useful for general purposes, as they are always ready for action, and are able to fight their guns on many occasions when the others are obliged to shut their lower deck ports. The same causes exist, in my opinion, for substituting a well-arranged two-decked ship for one of three decks, and are the reasons for my making the foregoing proposal.

Art. XXVII.—*On the Change in the Apparent Distances of Heavenly Bodies, by Refraction.* By Charles Blackburn, Esq., B.A., Second Mathematical Assistant at the Royal Naval College, Portsmouth.

The error (as far as relates to refraction) in the apparent distances of heavenly bodies whose altitudes are equal, is independent of the particular values of the altitudes.

Let S S' (Fig. 99) be two heavenly bodies whose altitudes are equal, $Z\,S$, $Z\,S'$ vertical circles; $S\,S'$ an arc of a great circle, ZD an arc of a great circle bisecting the $\angle\ S\,Z\,S'$, cutting, and therefore bisecting, $S\,S'$ in D; let also the zenith distances $Z\,S$ and $Z\,S'$ be called Z and Z', and the distance $S\,S' = D$.

Then since refraction takes place wholly in a vertical, the change in the apparent places of S and S' by refraction, will make no alteration in the angles $S\,Z\,D$ and $S'\,Z\,D$; we have therefore by the principles of the differential calculus,

$$d\,(S\,D) = d\,Z\,S \times \cos.\,Z\,S\,D \quad (1)$$

but $\cos.\,Z\,S\,D = \cot.\,Z\,S \times \tan.\,S\,D$; and therefore by substitution in (1) we have

$$d\,(S\,D) = d\,(Z\,S) \times \cot.\,Z\,S \times \tan.\,S\,D;$$

$$\text{that is, } d\frac{D}{2} = d\,(Z) \times \text{cot. } Z \times \text{tan. } \frac{D}{2} \quad (2)$$

Again, since refraction varies as the tan. of the zenith distance nearly, we have

$$d\,(Z) : \text{hor. refraction} :: \text{tan. } Z : \text{Rad}$$

$$\text{that is, } d\,(Z) : \rho :: \text{tan. } Z : \text{Rad}$$

$$\therefore\ d\,(Z) = \rho \times \tan Z;$$

substituting this value of $d\,Z$ in equation (2) we have

$$d\left(\frac{D}{2}\right) = \rho \times \text{tan. } Z \times \text{cot. } Z \times \text{tan. } \frac{D}{2}$$

$$\text{or } d\,(D) = 2\rho \times \text{tan. } \frac{D}{2},$$

from which it appears that the variation in the apparent distance of the two bodies is independent of the particular values of the altitudes.

Cor. 1. If the bodies be 90° distant, then $d\,(D) = 2\rho$, or the error in the apparent distance is twice the hor. refraction.

Cor. 2. Hence the error in the apparent distance of two fixed stars will be the same for all altitudes, provided those altitudes be equal.

ART. XXVIII.—*Notice of a Paper by* M. ARAGO, *on the Explosions of Steam Boilers, in the Annuaire du Bureau des Longitudes for* 1830.

M. ARAGO prefaces his observations with an account of the principal explosions of steam boilers which have taken place, especially those which involve the case of the greatest danger,—that in which the explosion is attendant on the opening of the safety valve, and is preceded by a diminution in the tension of the steam. Of the means to be taken for the prevention of these accidents, he says, "If we could be certain that the heat of the furnaces should never exceed a predetermined limit, no further precaution would be necessary. But when the manner

of supplying a large furnace with fuel is known, and how much the degree of combustion depends not only upon the nature of the coal, but also upon its size, upon the greater or less degree of care in spreading it upon the grate, and even on the state of the atmosphere, we should be quite convinced of the necessity of abandoning the idea of deriving the means of security from any practicable attention to the furnace."

As the explosion of a steam boiler is caused by the force of the steam overcoming the tenacity of the material of which the boiler is composed, it is evident that however strong a boiler may be, it must eventually burst, if the steam is allowed to accumulate in it. The author of the paper explains the various contrivances which have been proposed to prevent accumulation; and observes that though there are obstacles to any considerable increase of aperture, it would be advantageous to have the safety valves with as large openings as practicable; the more especially, as recent experiments on the flow of elastic fluids through small orifices, present some curious phenomena in connexion with this subject. "It has been found that if a light disk is placed in, and perpendicular to, a current of steam issuing from an aperture made in a high-pressure boiler, it will not always be repelled. At a short distance from the opening, the plate, which is acted upon by two opposite forces, the steam acting from the aperture, and the atmospheric pressure acting in an opposite direction, is in consequence of an equilibrium between these two forces, suspended in the air without motion." If the orifice be heated, more astonishing results are obtained. In some experiments made by Mr. Perkins, which are reported in Professor Silliman's journal, a hole of a quarter of an inch in diameter was made in the side of a generator, with the engine working at thirty atmospheres; the iron at the aperture was made red-hot, and while it continued heated, no steam was observed to issue. On the contrary, the steam was found to issue with immense violence when the metal became cool.

Plates composed of a mixture of metals which will fuse at a determined and low temperature, are sometimes used for safety valves; on the principle that steam cannot have a high degree of elasticity, without at the same time having a high tempera-

ture; and as the temperature necessary to produce a tension of a certain number of atmospheres is known, if the tension at which steam is required be determined, a plate of alloy may be made, which will melt at any higher temperature than is necessary to produce this.

The objections to these plates are, that they must necessarily gradually soften in approaching to their fusing temperature, and therefore may give way under less than the required tension of steam; and also, "when the plate is melted, the whole of the steam will escape through the aperture which is formed in the boiler. It will take considerable time to replace the plate, to re-fill the boiler, and to heat the water; and during all this time, the engine is perfectly useless. In a steam boat, in many cases, and especially near land, this sudden deprivation of the power of motion might be the occasion of a very serious accident." Another important objection is, that "it is in the power of the engineer to render these plates useless, by directing a stream of cold water over their surfaces."

A similar expedient is the having parts of the boiler calculated to give way under certain determined pressures. This has the same objection as the fusible plate, that of allowing the total escape of the steam; it has however the advantage of being more beyond the control of the engineer.

The mercurial guage is a bent tube containing mercury, having one leg communicating with the boiler, and the other open to the atmosphere. This M. Arago prefers to any other safety valve, and provided the aperture is of sufficient size, he considers it a security against all cases of danger from the *gradual* accumulation of steam. "The common safety valve gives no indication of the degree of tension of the steam until the moment it rises, and the fusible plate tells nothing until it melts; and in both cases the engineer learns suddenly that the steam has reached the limit which cannot be passed with safety, but he has no warning of its approach to it. The mercurial guage, on the contrary, informs him at every instant the exact degree of tension which the steam has acquired."

On the subject of previous proof, M. Arago remarks that the proof must be made under different circumstances from those which are attended with danger of explosion—the proof is

necessarily a gradual pressure on cold metal; and the circumstance of danger is, sudden pressure on heated metal. The tenacity of iron, the most usual material for boilers, is extremely diminished by heat; forged iron at a dull-red heat, has but one-sixth the tenacity of the same metal when cold; and, therefore, it is evident that a boiler might be on the point of explosion, without there being any indication of pressure on the safety valve. Another objection is, that proof must be made when the boiler is new, and exposure to the action of the fire very soon injures it considerably.

M. Arago has adopted the theory of Mr. Perkins on the phenomena of the sudden generation of steam. The foundation of this theory is, that steam may have a very high degree of temperature, without a corresponding increase of power; and that when in this state, if heated water is mixed with it, an instant formation of steam with great elastic power will ensue. The want of tension in the steam at the moment preceding the explosion, is accounted for from its being suddenly cooled by coming in contact with the cooler sides of the cylinder.

The paper also contains a brief outline of several other theories, especially that of M. Marestier,[1] which differs from Mr. Perkins's in accounting for the sudden generation of the steam, by attributing it to the immersion of part of the overheated surface of the boiler beneath the water.

M. Arago cites some experiments which are in opposition to the theory of M. Marestier; as they prove that steam is actually more quickly generated by the contact of water with metal heated to a moderate than to a great degree. "A drop of water thrown into an iron spoon heated to white heat, was converted into steam in 40″; at the expiration of which, a second drop was let fall; the spoon having cooled during this time, the evaporation only occupied 20″. The drop which succeeded immediately after this second, disappeared in 6″; a fourth drop in 4″; a fifth in 2″; and lastly, a sixth, in an incomputably short space of time."

Another theory of explosions is that of a M. Gensoul, of Lyons; which is, that when a metallic vessel contains a fluid under a high

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[1] See Art. 17, Vol. 2, of this work.

pressure, and is subjected to a sudden impact, it will break, though it would have borne very considerably greater force acting gradually. In the case of the steam boiler, the blow is supposed to be caused by the sudden re-action, incidental to the opening of the safety valve. To this M. Arago objects, that though the fact of fracture may be correct when applied to a vessel filled with an incompressible fluid, as water, it does not follow that it should be so with a compressible fluid, as steam; and also, that the supposition involves the necessity that the steam should have great elasticity at the instant preceding the explosion, which is contrary to fact; and consequently, although this cause may probably operate in some cases, it is insufficient as a general explanation of the phenomena under consideration.

Various speculations have also been advanced as to the formation of gas of an explosive nature in the interior of the boiler; as that hydrogen gas may be formed by the contact of the steam with the heated sides of the boiler. M. Arago admits the possibility of this, but observes that, as hydrogen gas alone is not explosive, the only inconvenience resulting from its formation is, that it must pass with the steam into the working cylinder, and as it is not susceptible of condensation, it can only be got rid of by a loss of power: and therefore that this may be one of the reasons why the engine often appears to have lost a part of its velocity at the instant preceding the explosion.

Some engineers suppose that the hydrogen escaping through some flaw in the boiler, may become mixed with the air in the furnace, and thus explode. Others say that carbonic hydrogen gas is furnished by the coals in the furnace, pure hydrogen by the decomposition of water which escapes through flaws in the boiler, and oxygen from the undecomposed part of the current of air which passes through the furnace. M. Arago admits that it is possible that a collection of this explosive mixture may be formed in the furnace, and mentions several explosions which must have been caused by some means similar in nature to this.

"To prevent these accidents, it is necessary, as much as is possible, to avoid all sudden bends or elbows in the flues of the furnace, as it is principally in such places that an accumulation can take place. It is also necessary that the register of the chimney should not be too closely shut, for if the air in the

chimney cannot escape, it will become gradually saturated with the gas which escapes from the coals, until the combination becomes explosive. To prevent, as much as possible, the gas from escaping from the coals without being consumed, the openings between the bars of the grate should be wide, and the fire should only be fed with small quantities of coal; as when large quantities are heaped on, if the coal is at all of a bituminous nature, it forms into a thick cake, which is almost impenetrable to the flame, and consequently a great quantity of unconsumed carbonic hydrogen will escape."

Another source of danger mentioned by M. Arago, arises from the quality of the water with which the boilers are supplied; if it is not pure, a deposit is formed, which being a bad conductor of heat causes the metal of the boiler to acquire far greater heat than the water which it contains; this not only occasions a great waste of combustion, but from the diminished tenacity of the iron, a great danger of explosion is incurred; and besides, if the crust should break, the water will suddenly get at the heated metal, which would suffer by the contact; and if it were cast iron, it would probably burst.

Our limits will not permit of a more extended notice of this paper, which is valuable and highly satisfactory, because being the result of considerable research, we find that the opinions which are already entertained, both as to the cause and prevention of danger from steam, receive confirmation from it.

Art. XXIX.—*A List of the Patents which have been taken out since the* 1*st of July*, 1830, *for Inventions or Improvements connected with Naval Affairs; with extracts of Specifications, &c.*

To Matthew Uzielli, of Clifton-street, Finsbury-square, in the county of Middlesex, gentleman, for improvements in the preparation of certain metallic substances, and the application thereof to the sheathing of ships and other purposes. Communicated by a foreigner. Dated July 6th, 1830.

To Thomas Bulkeley, of Albany-street, Regent's-park, in the county of Middlesex, M.D., for certain improvements in pro-

pelling vessels, which improvements are also applicable to other purposes. Dated July 19th, 1830.

To John Ruthven, of the city of Edinburgh, engineer and manufacturer, for an improved machinery for the navigating of vessels and propelling of carriages. Dated August 5th, 1830.

To William Dobree, of Fulham, in the county of Middlesex, gentleman, for an independent safety-boat of novel construction. Dated August 5th, 1830.

To Robert Clough, of Liverpool, ship-broker, for an improved supporting block, to be used in graving docks, and for other purposes. Dated August 5th, 1830.

To Henry George Pearce, of Liverpool, in the county of Lancaster, master-mariner, Richard Gardiner, and Joseph Gardiner, of the same place, merchants, for an improved fid. Dated September 7th, 1830.

To William Church, esquire, of Haywood-house, Birdeslygreen, near Birmingham, in the county of Warwick, for certain improvements in the construction of boats and other vessels, a part of which improvements are applicable to the construction of carriages. Dated September 21st, 1830.

To Richard Pering, of Exmouth, in the county of Devon, esquire, for an improvement or improvements in anchors. Dated October 6th, 1830.

To Jeffrey Shores, of Blackwall, in the county of Middlesex, boat-builder and ship-smith, for an improvement or improvements on tackle and other hooks, which he denominates "the self-relieving hooks." Dated November 1st, 1830.

To John Collinge, of Lambeth, in the county of Surrey, engineer, for an improvement or improvements on the apparatus used for hanging or suspending the rudders of ships or vessels of different descriptions. Dated November 1st, 1830.

To George Givinett Bompas, of Fishponds, near Bristol, esquire, M.D., for an improved method of preserving copper and other metals from corrosion or oxidation. Dated November 4th, 1830.

Extracts from Specifications, and Remarks.

Extracts from the Specification of Mr. P. C. De la Garde's Improvements in Fidding and Unfidding Masts, and in Masting and Rigging of Vessels.—The improvements in masting and

rigging vessels consist of some of the lower shrouds being attached to a frame or collar immediately below the trestle-trees, in such manner as to pull fair from the mast, and to lie close to it out of the way of the yard, which may therefore be braced up sharper or nearer to the line of the keel, than can be done by the ordinary method. And further, in extending the foot of a main-course between a block through which the tack is reeved, traversing on an iron spindle or horse, which spreads into a crutch at the outer end, fitting a chest-tree projecting from the side of the vessel, so as to be occasionally raised up from off the deck, and the inner end of which is chased into a strong stanchion, or other convenient part, fixed on the deck; and a boom, on the outer end of which a block is lashed having the sheet reeved through it; so that the foot of the course shall be parallel to the yard, whether it be braced up to an angle more or less acute, and the sail thereby be rendered flat. The horse or spindle does not stand square with the vessel, but from the chest-tree is carried obliquely forward. The block has one large eye by which it traverses on the spindle, and two others projecting transversely, to which are attached ropes, whereof one reeves through a sheave-hole cut in the chest-tree, to draw the block out, and the other draws it inward. The boom forms no part of this invention. The same may be applied to a fore-course, the spindle extending from the cat-head or a boomkin to the figure block or other convenient part; and to a cross jack sail.

The improvements, as regards fidding and unfidding masts, consist of two wedges (forming a prismatic compound), being combined together, and prevented from working off, the one from the other, by an apparatus of catches and levers, adapted to be acted on by tackles communicating with the deck, which apparatus forms shoulders, so that the wedges cannot work out separately or together, until the catches be lifted out of the mortises made to receive them. The wedges have shackles at their large ends, whereby they are by tackles drawn out of the fid-hole; and likewise at their small ends, whereby (the action of the tackles being reversed) they are drawn into the fid-hole—and further in, rollers working in brackets or sockets fixed on the trestle-trees, and of a frame, containing rollers fixed in the upper side of the lower wedge whereon the under side of the upper wedge

rests; and in a frame containing rollers fixed in the upper part of the fid-hole, whereby the friction being diminished, the wedges may be more easily introduced or withdrawn. A second fid has only one apparatus of catches and levers, the shoulder at its other end being formed by the shackle of the under wedge. The fid-hole rollers are omitted when this fid is used, as may be the rollers of the wedge.

Observations communicated by the Patentee.—The shrouds crossing in front of the mast counteract the twisting action of the topmast. Making a more open angle, and being set up abreast of the mast, without cat-harpening, they better resist the rolling of a vessel. This method combines the qualities of fore and aft and of square rigging.

The superiority of the latter, when before the wind, is admitted and explained. Its inferiority, when sailing near the wind, though equally evident, depends on causes comparatively obscure. Some have been recognised, but others of greater importance have been overlooked, and consequently the various attempts at improvement have been attended with very doubtful success. Fore-and-aft-rigged vessels, close hauled, trim their principal sails to a proper angle with the keel: but square-rigged vessels, even at six points from the wind, trim only one sail to advantage. Their yards can rarely be braced within thirty-five degrees of the midship-line—yet twenty-three is the angle required; or, considering that the sail will belly to a certain extent, twenty-five in practice. But the foot of a course (extending from the weather chest-tree or boomkin to the lee shrouds) makes a still more open angle: and from the foremost lee shroud to the clue forms with the leech a mere bag, holding the wind. The stay-sail and jib, on the contrary, make too acute an angle; and if their sheets are eased off, they belly and hold the wind. The advantage of bracing the yards sharp up has been disputed, although it is evident that the action of the wind on a square course, a brig's mainsail, or a ship's driver, is precisely similar, and consequently that they should trim to the same angle. The upper and lower portions of square courses being (in consequence of the present injudicious mode of disposing their tacks and sheets) placed in opposition as soon as the wind gets before the beam, those fine sails, notwithstanding their vast extent and advantageous

situation, lose, even under skilful management, two-thirds of their propelling power, their tendency to produce lee-way being augmented in the same proportion.

In the proposed improvements the square sails are unaltered in size or shape, and their effect whilst quartering or sailing before the wind is unchanged. They will, when close-hauled, act as lug sails—the courses very superior to any sails hitherto used in European ships. The yards may be braced up within sixteen degrees of the line of the keel without forcibly pressing the lee rigging or stays. This is more than would ever be required in sailing, but in working a ship it is highly important.

In tacking, the square sails would draw when only five points from the wind. As the ship came to the wind, the fore yards might be braced up gradually, so as not to check her way by being too soon taken aback. On the opposite tack, the square sails would fill as soon as the jib. The vessel would therefore depend on her way for a much smaller space than at present; the evolution would be performed in half the time now occupied, and the risk of missing stays be very much diminished. In veering, the fore-yards being nearly perpendicular to the wind, would cause the vessel to fall off more rapidly.

Figs. 100 and 101 represent two ships close-hauled at six points from the wind. Fig. 100, rigged according to the proposed method, all her sails making an angle of 23° with the line of her keel. The courses trimmed quite taught by booms and traversing tacks. The driven boom over the quarter. The foot of the jib being stretched by a light boom, it corresponds with the other sails. Fig. 101, rigged in the usual mode. The driven boom at the proper angle, 23°. The main and fore yards at an angle of 40°. The foot of each course still more open, and bent to the ship's side at the lee shrouds. The jib at an angle of 12°.

The importance of readily striking and replacing upper masts, without slackening their standing rigging, is apparent. Furnished with the apparatus described, top-masts of the largest size can, under any circumstances of weather, be expeditiously unfidded at sea, without a man going aloft. An ordinary merchantman's crew can strike all the top-masts at one time, and which is almost of equal importance, get them up again with ease, even though the vessel may labour considerably.

PAPERS

ON

NAVAL ARCHITECTURE,

&c.

Art. XXX.—*Chapman's Work on Ships of War, translated from the Swedish, by* Wm. Morgan, *of His Majesty's Dock-yard at Sheerness.*—(Continued from page 281.)

Chap. XI.—*On the Area of Sails.*

31. It is said, in the Introduction, that all the ships in a fleet, with the same sails set, should sail equally well, consequently the areas of sail of the ships must be in the same proportion to each other as the resistances they experience from the water in their progress. But this circumstance must also be attended to: that if two ships are in all respects similar, and rigged in the same proportion, but the one larger than the other, the larger ship always sails best.

We must hence conclude, that a larger and heavier body has a greater power of continuing its motion than a less body; that is to say, the weight of the body, when it has obtained a certain velocity, contributes to the continuation of its motion. Hence it follows, that the area of the sails, which is the force which carries the ship forward, will be directly as the resistance of the ship, and reciprocally as the displacement, raised to a certain power, which power cannot be known in any other manner than by trial; and it has at length been found, by much investigation, that the index of this power will be about $= 0{,}4$. Thus the area of the sails will be as $\frac{R}{\frac{1}{2}D^{0,4}}$, R being $=$ the resistance in Table 26, and $D =$ the displace-

ment. By a continuation of the same investigation it has also been found, that all ships of the line will have their area of sail in relation to their stability, when the breadth of the lower edge of the main-top sail is $= 10{,}21 \sqrt{\frac{R}{\frac{1}{2} D^{0,4}}}$; viz. when all the sails of a ship have the form and relative proportions given in the Treatise on the Area of Sail for Ships of the Line, § 7, et seq.

32. In the preceding § the lower edge of the main-topsail is found, from which the area of sail is found; but previously to proceeding further with the subject, it is absolutely necessary that the situation as to height of the centre of gravity of the ship should be known, for finding which, two methods are given: 1st, By calculation, which is here used, for finding the situation as to height of the common centre of gravity of the ship itself, of the whole armament, masting and rigging, ballast and of the whole fitting, when ready for sea; and it has been found that the situation of the centre of gravity of the whole ship above the water-line is, for a ship of 110 guns = 2,8 feet, for a ship of 94 guns = 2,384 feet, for a ship of 80 guns = 2,22 feet, for a ship of 74 guns = 2,23 feet, for a ship of 66 guns = 2,24 feet, and for a ship of 52 guns = 2,1 feet.

That the centre of gravity has been placed very nearly in its true situation, at least not far from it, may be judged of by what follows: the *Victory*, an English ship of 100 guns, which was built about 60 or 70 years ago, according to appearance more for show than for use, was a ship with a very full bottom, and had therefore its metacentre not more than 3,8 feet above the water-line, when armed; and if we suppose that this fulness brought down the centre of gravity two-thirds of a foot, but not more, on account of its high upper works, lower than in our ships of 110 guns, which is = 2,8 above the water-line, then we have $2{,}8 - 0{,}66 = 2{,}14$, which was the height of the centre of gravity of the *Victory* above the water-line. When this is subtracted from 3,8, that is, $3{,}8 - 2{,}14$, we have $1{,}66 = 1\frac{2}{3}$ foot, which was the distance between the centre of gravity and the metacentre in the *Victory*; and as this ship was lost in a violent storm in the year 1745 (if I am not mis-

taken), it probably was caused by a high wave, which produced so great a heeling that the ship upset. Hence it appears of what importance it is, when a ship's draught is made, that the situation of the centre of gravity should be known, that in case the two centres are too near to each other, the length of the ship, and especially the breadth, may be increased.

2ndly. To find in a harbour, where all sorts of ships are fitted, by means of heeling them, the situation of their centres of gravity as to height, in the manner described in the new Transactions of the Royal Academy of Sciences, Vol. VIII., for the first quarter of the year 1787: viz. *On the true method of finding the situation of the centre of gravity of a ship as to height, when afloat, with or without a full armament, when in possession of the ship's draught.* And I most particularly recommended, that such experiments should be ordered, and the results, with all the circumstances of a ship's stowage, &c. accurately noted, as highly important to the practical application of theory in designing a ship correctly.

In the following Table are inserted the weight of the service of the guns and their moment, to heel a ship, with the moment of the ship, to resist the inclination, &c.

Table No. 27.

Weight of the Men at the Guns to Leeward, &c.

GUNS.	110	94	80	74	66	52
	No.	No.	No.	No.	No.	No
Lower battery......................	48-pounder 15	42-pounder 15	42-pounder 15	36-pounder 14	36-pounder 13	24-pounder 13
Men at the guns....................	15 men .. 225	13 men .. 195	13 men .. 195	13 men.. 182	13 men.. 169	9 men.. 117
Wt. in cub. ft. of water, at 2,7 per man	607,5	526,5	526,5	491,4	456,3	316
	No.	No.	No.	No.	No.	No.
Second battery.....................	36-pounder 16	30-pounder 16	24-pounder 16	24-pounder 15	24-pounder 14	18-pounder 13
Men at the guns....................	13 men .. 208	11 men .. 176	9 men.. 144	9 men.. 135	9 men.. 126	9 men.. 117
Wt. in cub. ft. of water, at 2,7 per man	561,6	475,2	388,8	364,5	340,2	316
	No.	No.				
Third battery......................	24-pounder 15	18-pounder 16	—	—	—	—
Men at the guns....................	9 men .. 135	9 men .. 144	—	—	—	—
Wt. in cub. ft. of water, at 2,7 per man	364,5	388,8	—	—	—	—
	No.		No.	No.	No.	
Quarterdeck and forecastle..........	12-pounder 9	—	12-pounder 9	12-pounder 8	12-pounder 6	—
Men at the guns....................	7 men .. 63	—	7 men .. 63	7 men.. 56	7 men .. 42	—
Wt. in cub. ft. of water, at 2,7 per man	170,1	—	170,1	151,2	113,4	—
Men with small-arms in the waist....	49	44	40	38	36	30
Wt. in cub. ft. of water, at 2,7 per man	132	119	108	103	97	81

TABLE No. 27.—(*continued.*)

GUNS.	110	94	80	74	66	52
Men with small arms on the poop or quarterdeck	51	46	42	40	38	24
Weight in cubic feet of water, at 2,7 per man	138	124	113	108	103	65
Total weight of the men at the guns in cubic feet of water = P	1974	1634	1306	1218	1110	778
Common centre of gravity of all the men at the guns from middle line of ship = b	16,5	16,25	16,00	15,5	15,2	14,4
Moment of men at guns to leeward = $b\,P$	32571	26552	20896	18879	16872	11203
Displacement = D	152875	128297	107400	96422	88722	66753
$\frac{D}{20}$ = the planking	7644	6415	5370	4821	4436	3338
Displacement with planking = Q	160519	134712	112770	101243	93158	70091
Metacentre above the water (Table 23) =	6,652	6,366	6,529	6,637	6,640	7,107
Common centre of gravity above water = v	2,800	2,384	2,220	2,230	2,240	2,100
Distance between the metacentre and the centre of gravity = a	3,852	3,982	4,309	4,407	4,400	5,007
Moment to resist inclination = $a\,Q$	618319	536423	485926	446178	409895	350866
$\frac{B}{2}$	28,135	26,66	25,46	24,755	24,23	22,50

33. To find the moment of the power of the sails, M, which, agreeably to the drawing, is $= \frac{\sin. s. \, a\,Q}{\text{rad.}} - \frac{\cos. s. \, b\,P}{\text{rad.}}$ when the inclination is $= 7$ degrees. See the operation in the treatise on the area of sails for ships of the line, § 13. The following is an example for a ship of 74 guns.

$$\log. \sin. 7^\circ = 9{,}0858945$$
$$a\,Q = 446178 = 5{,}6495082$$
$$4{,}7354027 = 54376$$
$$\log. \cos. 7^\circ = 9{,}9967507$$
$$b\,P = 18879 = 4{,}2759790$$
$$4{,}2727297 = 18738$$

Moment of the power of the sails, $M = 35638$

The same operation is performed for the other ships, and the results, &c. are inserted in the following Table.

TABLE No. 28.

		110	94	80	74	66	52
Moment of the power of the sails, M		43026	39020	38527	35638	33207	31641
From the water-line to the upper side of the second deck $= A\,B$	=	12,43	12,32	12,55	12,55	12,50	11,87
	v =	2,800	2,384	2,220	2,230	2,240	2,100
Fig. 102	$A\,B - v$ =	9,63	9,94	10,33	10,32	10,26	9,77
	$B\,C$ .. =	6,2	6,0	5,8	5,7	5,6	5,4
	$A\,C = d$ =	15,83	15,94	16,13	16,02	15,86	15,17

If the breadth of the lower edge of the main-topsail is put $= x$, then the moment of all the eight sails from the centre of gravity is $= \overline{d + 0{,}6264\,x + 0{,}4548\,x} \,.\, 2{,}1277\,x^2 + \overline{d + 0{,}56\,x} \,.\, 0{,}3546\,x^2$ (Area of Sails, § 11), but instead of $C\,T$ being $0{,}56\,x$, it is for ships of three decks $= 0{,}616\,x = f\,x$, and for ships of two decks $= 0{,}589\,x = f\,x$, and thence

the moment of the eight sails $= \overline{d + 1{,}0812\, x} \,.\, 2{,}1277\, x^2 +$ $\overline{d + f x} \,.\, 0{,}3546\, x^3 = \dfrac{63\, M}{0{,}4619 \,.\, 2{,}29} = 59{,}56\ M$, which for the different ships is as follows;

110...	$39{,}295\, x^2 + 2{,}518\, x^3$	$= 59{,}56\, M$	$= 59{,}56 \,.\, 43026$;	hence $x = 95{,}64$
94...	$41{,}568\, x^2 + 2{,}518\, x^3$	$= 59{,}56\, M$	$= 59{,}56 \,.\, 39020$;	hence $x = 92{,}16$
80...	$40{,}039\, x^2 + 2{,}509\, x_3$	$= 59{,}56\, M$	$= 59{,}56 \,.\, 38527$;	hence $x = 91{,}84$
74...	$39{,}766\, x^2 + 2{,}509\, x_3$	$= 59{,}56\, M$	$= 59{,}56 \,.\, 35638$;	hence $x = 89{,}36$
66...	$39{,}369\, x^2 + 2{,}509\, x^3$	$= 59{,}56\, M$	$= 59{,}56 \,.\, 33207$;	hence $x = 87{,}18$
52...	$37{,}650\, x^2 + 2{,}509\, x_3$	$= 59{,}56\, M$	$= 59{,}56 \,.\, 31641$;	hence $x = 85{,}69$

When all the ships incline to 7 degrees.

34. To find the angle of inclination, when the breadth of the lower edge of the main-topsail is in proportion to 10,21.

$\sqrt{\dfrac{R}{\frac{1}{2} D^{0,4}}}$, (§ 31) the power of the moment of the sails, M', is to be first found.

Table No. 29.

Breadth of the lower edge of the main-topsail $= 10{,}21. \sqrt{\frac{R}{\frac{1}{2} D^{0,4}}} = x$		M'	In relation to the stability.		In relation to the resistance, $\frac{R}{\frac{1}{2} D^{0,4}}$ (§ 31).	
			Breadth of the main-topsail $= x$	Area of the eight sails $= 2{,}4823\ x^2$.	Breadth of the main-topsail $= x$	Area of the eight sails $= 2{,}4823\ x^2$.
110	94,99	$\frac{39{,}295\ x^2 + 2{,}518\ x^3}{59{,}56} = 42189$	95,64	22706	94,99	22396
94	92,06	$\frac{41{,}568\ x^2 + 2{,}518\ x^3}{59{,}56} = 38900$	92,16	21083	92,06	21040
80	89,89	$\frac{40{,}039\ x^2 + 2{,}509\ x^3}{59{,}56} = 36029$	91,84	20937	89,89	20059
74	88,30	$\frac{39{,}766\ x^2 + 2{,}509\ x^3}{59{,}56} = 34208$	89,36	19822	88,30	19353
66	86,88	$\frac{39{,}369\ x^2 + 2{,}509\ x^3}{59{,}56} = 32614$	87,18	18867	86,88	18737
52	80,45	$\frac{37{,}650\ x^2 + 2{,}509\ x^3}{50{,}56} = 26026$	85,69	18227	80,45	16066

The inclination caused by the sails is $=$ sin. $s = \frac{\text{Rad. } M}{a\ Q}$,

and by the men to leeward is $=$ tangent $s = \frac{\text{Rad. } b\ P}{a\ Q}$.

TABLE No. 30.

Inclination when the sail is in relation to the stability; the power of the moment of the sail = M.				Inclination when the sail is in relation to the resistance, the power of the moment of the sails = M'.
Guns.	By the sail.	By the men.	Total.	Example of a ship of 74 guns.
110	3° 59′	3° 1′	7°	Rad. M = 14,5341277
94	4 10	2 50	7	$a\ Q$ = 5,6495082
80	4 33	2 27	7	Inclination by the sail = 4° 24′ = 8,8846195
74	4 35	2 25	7	Rad. $b\ P$ = 14,2759790
66	4 39	2 21	7	$a\ Q$ = 5,6495082
52	5 10	1 50	7	Inclination by the men = 2° 25′ = 8,6264708
				Total inclination = 6° 49′.

110 { sail = 3° 55′; men = 3 1; total = 6 56	94 { sail = 4° 9′; men = 2 50; total = 6 59	80 { sail = 4° 15′; men = 2 27; total = 6 42
74 { sail = 4 24; men = 2 25; total = 6 49	66 { sail = 4 34; men = 2 21; total = 6 55	52 { sail = 4 15; men = 1 50; total = 6 5

35. To find the alteration which must be made in a ship's breadth, in order that with the latter power of the moment of the sails, M', the inclination may be $= 7$ degrees.

In the first place, the distance, a, between the centre of gravity of the ship which is fixed, and the metacentre which is changed, is determined; the ship's displacement and the length are also constant.

The difference between the former and latter value of a is to be added to $\frac{\int \frac{2}{3}\, y^3\, d\, x}{D} = p$, (Table 23) if the latter value of a' is the greater, but is to be subtracted if the latter is the less.

To find the distance a' between the centre of gravity and the

metacentre, we have $M' = \frac{\sin.\ s.\ a\ Q}{\text{Rad.}} - \frac{\cos.\ s.\ b\ P}{\text{Rad.}}$; hence $a' = \frac{\text{Rad.}\ M' + \cos.\ s.\ b\ P}{\sin.\ s.\ Q}$; $\frac{\int \frac{2}{3} y^3\, d\,x}{D} = p$, but as $\frac{\frac{2}{3}\, d\,x}{D}$ is constant, y^3 varies as p, also $p : p' :: y^3 : y'^3$; therefore $y' = \overline{\frac{p'\,y^3}{p}}\Big|^{\frac{1}{3}}$.

TABLE No. 31.

	110	94	80	74	66	52
In relation to res. } M' =	42189	38900	36029	34208	32614	26026
$b\ P$ =	32571	26552	20896	18879	16872	11203
Q =	160519	134712	112770	101243	93158	70091
y =	28,135	26,62	25,46	24,755	24,23	22,50
p =	15,204	14,445	14,107	13,916	13,721	13,43
a =	3,852	3,982	4,309	4,407	4,400	5,007
a' =	3,809	3,975	4,131	4,291	4,348	4,349
$a - a'$ =	0,043	0,007	0,178	0,116	0,052	0,658
$p - \overline{a-a'} = p'$ =	15,161	14,438	13,929	13,800	13,609	12,772
y' =	28,108	26,656	25,352	24,686	24,199	22,126
$2\,y' = B'$ =	56,216	53,312	50,704	49,372	48,398	44,252
B =	56,270	53,320	50,920	49,510	48,460	45,000
Diff. $B - B'$ =	0,054	0,008	0,216	0,138	0,062	0,748

Example of the calculation for a ship of 74 guns.

Rad. M'			= 34208
$b\ P$ = 18879	=	,2759790	
Cos. 7°	=	,9967507	
Cos. $s.\ b\ P$ . . .	=	,2727297	= 18738
Rad. M + cos. $s.\ b\ P$	=	,7238332	= 52946
Q = 101243	=	,0053651	
sin. 7°	=	,0858945	
		,0912596	= 4,407 = a
$\frac{\text{Rad.}\ M + \cos.\ s.\ b\ P}{\sin.\ s.\ Q}$	=	,6325736	= 4,291 = a'
			0,116 = $a - a'$

$$\begin{array}{rrl} p = & 13,916 & \\ a - a' = & 0,116 & \\ \hline & 13,800 & = p'. \end{array}$$

Example of the calculation for finding the new half-breadth, y'.

$$\begin{array}{rcrcr} y & = & 24,755 & = & 1,3936629 \\ & & & & 3 \\ \hline & & & & 4,1809887 \\ p' & = & 13,800 & = & 1,1398791 \\ \hline & & & & 5,3208678 \\ p & = & 13,916 & = & 1,1435144 \\ \hline & & & & (3)\ 4,1773534 \\ \hline y' & = & 24,686 & = & 1,3924511 \\ y & = & 24,755 & & \\ \hline y-y' & = & 0,069 & & \end{array}$$

We have at length found, 1st, the breadth of the lower edge of the main-topsail, all the ships being supposed to sail equally well: namely, 94,99, 92,06, 89,89, 88,30, 86,88, 80,45 feet, (table No. 29); 2ndly, how much less the ships incline thereby when close-hauled with the men at the lee guns; namely, 0° 4′, 0° 1′, 0° 18′, 0° 11′, 0° 5′ and 0° 55′ (table No. 30); and finally, how much the breadth of the ships must be diminished, that they may all incline to the same angle of 7°: namely, 0,054, 0,008, 0,216, 0,138, 0,062 and 0,748 foot (table No. 31), which differences are so inconsiderable in the ships of the line, that if they were constructed so much the less, it would not produce any diminution in their expense, the greatest difference in the whole breadth being not more than 0,216 = $2\frac{1}{2}$ inches for the ship of 80 guns; and the little diminution of 18 minutes in the inclination, facilitates the working of the guns more quickly. The effect will nevertheless be seen, when the breadth of the same drawing is diminished, the length and displacement remaining the same.

36. By reference to § 15, table 15, it is found that the area *A*, of the lower part of the foremost element, for a ship of 80 guns, is 1842,7. Divide the displacement, $D = 107400$, by the new breadth, $B = 50{,}704$ (§ 14); then $\frac{107400}{50{,}704} =$ 2118,2; when 1842,7 is subtracted from this quantity, there remains $275{,}5 =$ the area of the rectangle; its length is $= 181{,}38$ $= l-g$ (table No. 15); hence $e = \frac{275{,}5}{181{,}38} = 1{,}519$, which is the height of the rectangle; this height was before $= 1{,}469$, so that it is increased by 0,05 foot, which added to $\mathbf{k} = 15{,}867$, and this is equal to the new value of **k**, according to which the ⊕ is drawn, § 23. The water-line and half-breadth line are diminished in breadth, and all their ordinates in the same proportion, retaining the similarity of form.

As the breadth of the ship of 110 guns was at first 55,78, which was found to be too small by 0,49 foot, it was altered in the same manner, but with this difference, that in this case it was an increase, and therefore **k** was diminished, which occurred before these first rules, which are here inserted, were used.

For the same reason, we might also have altered the breadth of a ship of 80 guns; but as an increase of $2\frac{1}{2}$ inches in the breadth is regarded as inconsiderable, and as this little increase of breadth was in favour of the ship, no alteration took place.

With respect to the two-decked frigate of 52 guns, it is not intended to be in a line of battle, but must possess stability agreeably to the area of sails, namely, the breadth of the lower edge of the main-topsail x being $= 85{,}69$ feet; it thus becomes a better sailer than a ship of the line,—a quality which all frigates must possess.

Remark. It is to be here observed (table No. 30), that the larger ships of the line incline less, close-hauled, than the smaller ships, when not in action; but in action, the men stationed at the guns to leeward, occasion a greater inclination in the larger ships than in the smaller; consequently, the proper case is assumed (see the introduction) when the qualities of a ship of the line must come into consideration, which is: when

several ships are in action with an enemy, which is explained in the description of an engagement between two hostile fleets.—If, on the contrary, the qualities of a ship of the line had not been considered when in action, but only that all ships when sailing close-hauled, should sail and incline alike, in equally strong winds, with the same sails set, it would happen, that when they come into action, the larger ships would incline more than the smaller.

Suppose that a ship of 110 guns sails equally well, and has the same inclination with a ship of 74 guns, namely, 4° 24′, both sailing close-hauled; then the breadth of the ship of 110 guns would be diminished, so as to be 0,55 foot less than before; the consequence of which would be, that when both ships come into action with an enemy, and the men are at the guns to lee-ward, the ship of 110 guns would incline to 7° 41′, which is 52′ more than the ship of 74 guns; and as this inclination is too much, the sail must be diminished, and therefore the velocity will be less; thus the greater ship, which is designed to produce the greater effect, is inferior in respect to stability to the less, which cannot produce the same effect. Of ships so circumstanced a bad fleet is composed.

CHAP. XII.—*On the length of the Masts and Yards.*

37. From what has been said on the area and moment of the sails, in proportion to the resistance and stability of a ship, may be inferred; that a ship and its sails are to be considered together, as a bird and its wings, which constitute one body or machine; consequently in the consideration of a ship, especially of a ship of the line, the sails must be included. Thus the drawings of a ship are not complete without a rigging-draught: for this reason the following table is calculated (see "the area of sails, § 14 and 15"), by which the rigging-draught of every ship may be constructed. Only three of the draughts are here constructed, namely, for a ship of 110 and 74 guns, and for a two-decked frigate of 52 guns, fig. 103, by a scale which is only ⅛ part[1] of that of the drawings of the ships.

[1] The scale of the figures of this translation is half that of the original.

Table No. 32.

To find, from the Breadth of the Main-topsail, the Lengths of the Lower Masts and Top Masts, and the Proportions of all the Sails.

	110	94	80	74	66	52
Breadth of lower edge of main-topsail $\left(10{,}21\sqrt{\frac{R}{\frac{1}{2}D^{0,4}}}\right) = x$	94,99	92,06	89,89	88,30	86,88	85,69
From water-line to centre of gravity of ship, Fig. 102, A...............	2,80	2,38	2,22	2,23	2,24	2,10
From centre of gravity A to fid of top-mast $A\,C = d$.....................	15,83	15,94	16,13	16,02	15,86	15,17
From C to under edge of main-topsail $= C\,D = 0{,}6264\ x$	59,50	57,67	56,31	55,31	54,42	53,68
From D to upper edge of main-top $= D\,E = 0{,}1296\ x$	12,31	11,93	11,65	11,44	11,26	11,11
Length of the head above the top $= E\,Q = 0{,}1656\ x$	15,73	15,37	14,89	14,62	14,39	14,19
Length of main-mast from water-line to cap	106,17	103,29	101,20	99,62	98,17	96,25
Length of main-top mast $= C\,D + D\,E = 0{,}756\ x$	71,81	69,60	67,96	66,75	65,68	64,78
Its head $= \frac{1}{2}$ the head of main-mast	7,87	7,68	7,44	7,31	7,20	7,09
Length of topgallant mast to upper edge of cross trees $= 0{,}43\ x$	40,85	39,58	38,65	37,97	37,36	36,85
Depth of main-topsail $= 0{,}72\ x$	68,39	66,29	64,74	63,59	62,55	61,70
Between main-topsail and top-gallantsail $0{,}0232\ x$	2,20	2,14	2,09	2,05	2,02	1,99
Depth of topgallantsail $= 0{,}44\ x$	41,80	40,50	39,55	38,85	38,23	37,70
Topgallant mast above topgallantsail $= 0{,}05\ x$	4,75	4,60	4,49	4,42	4,35	4,28
Lower edge of fore-topsail below main-topsail $= 0{,}0366\ x$...............	3,48	3,34	3,29	3,23	3,18	3,14
Lower edge of mizen-topsail below main-topsail $= 0{,}0565\ x$	5,37	5,20	5,08	4,99	4,91	4,84
Mizen-mast-head above main-top $= 0{,}0151\ x$	1,45	1,43	1,36	1,33	1,31	1,29
Horizontal distance from fore-stay to foremast $= \sqrt{\frac{L\,h}{2{,}324}}$	58,28	56,05	54,13	52,69	51,70	49,66

TABLE No. 32.—(*continued.*)

	110	94	80	74	66	52
From topmast staysail tack to foremast $= \sqrt{\frac{Lh}{1,75}}$	77,40	74,43	71,88	69,97	68,65	65,95
From jib tack to foremast $= \sqrt{\frac{Lh}{1,226}}$	110,48	106,24	102,60	99,64	98,00	94,13
L = length of water-line, and h = distance from centre of gravity A to main-top.						
Bowsprit beyond topmast staysail tack $= \frac{L}{32}$	6,54	6,20	5,87	5,66	5,53	5,23
Breadth of upper edge of main-topsail $= 0,75\ x$	71,24	69,04	67,42	66,22	65,16	64,27
Breadth of upper edge of main-topgallantsail $= 0,54\ x$.	51,29	49,71	48,54	47,68	46,92	46,27
Head of foremast below head of mainmast, $= \frac{2}{3}$ head of mainmast	6,29	6,15	5,96	5,85	5,76	5,68
Mizenmast head above upper edge of main-top = 0,091 of mainmast head	1,43	1,40	1,35	1,33	1,31	1,29
Lower edge of mizen-topsail below upper edge of mizen-top = 0,688 of mizenmast head	7,79	7,61	7,37	7,24	7,13	7,03
Every thing which relates to the foremast is $\frac{8}{10}$ of that of the mainmast.						
All the dimensions of the sails of the mizenmast are 0,72 of those of the mainmast.						

From these proportions every thing is known which is necessary to determine the proper lengths of the yards. And thus we have the lengths of all the masts, when to the lower masts are added the parts below the water-line; and to the topmasts their lengths below the upper edge of the cross-trees; and to the bowsprit the part which comes within the stem.

The appearance of the lower edges of the main and fore topsails of a frigate of 52 guns, crossing each other so far, is not uncommon in rigging-draughts; but when the yards are braced so as to make an angle of three points with the middle line of the ship, the main yard-arm does not lock with the foresail, when the after sails are braced round in tacking, or the head-sails in coming about.

38. It is a common custom with us in getting up the topmast, to stay it so far forward, that the head of the mast is bent forward, and as the mast is kept fixed in its position by the shrouds and stays, the mast forms a curve aft, and the curvature is greatest at the lower yard; and when it has remained bent sometime, it never becomes straight again, and the mast is spoiled: also in consequence of the slings, which support the lower yard, lying against the fore part of the foremost cross-tree and over the cap, the mast-head is drawn forward: and it is for these reasons, the after shroud is allowed to go over the cap round the mast-head, which reaches about a foot above the cap.

Concerning the tops it is to be observed, that they should be as broad as possible, in order that the topmast shrouds may give the topmasts good support; but they should not however be broader than to allow the topmast backstays to clear the outer edge of the tops about three inches. Its rounding off at the fore part, should commence from the second topmast shroud from forward, and it should be rounded off as much as possible, because otherwise the topsail is prevented from being close-hauled, and the sail is destroyed. It follows that the channels should have sufficient breadth.

It should be remarked, that although the lower yards can be braced to about the same angle as the topsail yards, the courses can never be set advantageously, close-hauled, when the tacks and sheets are hauled in to the ship's sides; the fore-

most lee-shroud brings the foot of the sail so much to leeward, that the wind cannot produce an advantageous effect on it. This is assisted in some measure by the bowlines, but not sufficiently. I therefore let the following alteration be made in a new frigate of 40 guns: an iron arm was fastened to the foremost end of the mizen channel, of such a length that the block for the main sheet to leeward should come 6 feet without the ship's side, also the block for the main tack 5 feet within the ship's side or the gunwale. The foot of the mainsail becomes thus much straighter, and with the help of the bowline, the mainsail is brought to stand as sharply braced as the foresail. A similar alteration was made for the sheet of the foresail as for that of the mainsail; a little before the gangway, an iron arm of the form of a knee was placed outside the gunwale, to be swung fore and aft, when the boats should be hung over the gunwale; this arm was of such a length that it brought the sheet-block 5 feet without the gunwale: and as the fore tack may be brought as near the fore part of the head as it is wished, the foresail may be braced as sharp as the mainsail. And as it was found to answer well in a short cruize in the Baltic, it could not but be approved of by all good sailors.—By placing the block for the main tack in this manner, a free passage on the gangway within the gunwale was obtained forward on the weather side.

The driver is an excellent sail.

A circumstance will be now mentioned which deserves attention.

It frequently happens, when the gammoning and bobstays of the bowsprit are set up the first time, by means of the launch hanging at the extremity of the bowsprit, it curves downwards at the end, so that the lower pieces of which it is composed, although secured with wouldings and clinch-bolts which hold them together, draw one-fourth of an inch or more beyond the end of the upper pieces, by which the coaks of the bowsprit are injured, before the ship goes out of harbour; to the method of the operation there is no objection, but the execution of it should be less violent and more cautiously performed.

When the ship is either sailing or riding at anchor in a high sea, and pitches heavily, a continual working and rubbing of one

piece over the other is perceived, which would not be so great, if the coaks were not injured in the manner just mentioned. Nevertheless, as the preservation of the foremast and main top-mast depends wholly on the support of the bowsprit, it should be the object by all possible means to give it the necessary strength, which may be done in the manner shown in fig. 104: namely, with a beam of the mean siding and moulding between the lower and upper deck beams, the after end of which is secured to the forecastle in a proper manner, so that some play may be allowed: the foremost end is tapered a little and reaches to the fore-stay, coaked to the bowsprit, to the upper part of which the tree is fitted, it is also secured with some strong wouldings, and two bolts through both knightheads, the one above and the other under this beam, over which a third lashing of the bow-sprit can be laid.

Chap. XIII.—*To construct the Drawings of a Ship, without regard to the Relaxation-lines.*

39. It is above twenty years ago that I first considered that there was no well-established and fixed method of constructing a ship's drawings, that is, that when the length, breadth, and depth of a ship, with its displacement, were determined, it was not known, 1st, that the ⊕ section would come precisely in its proper place; 2ndly, whether its area was too great or too small; and, 3rdly, so to proportion the fulness of the fore body to that of the after body, that the centre of gravity of displacement might be at a given distance before the middle of the length of the ship.

This led me to investigate the subject, and to examine numerous draughts of many larger and smaller ships, in order to try if the areas of the sections abaft the ⊕ section, as well as before it, did not follow some regular progression; and I thought, in order to ascertain it, it would be best to divide the area of each section by the breadth of the midship section; the proportion of one section to another was thus expressed by the quotients: these quotients were set off perpendicularly from

the water-line on their corresponding section-line on the sheer draught, and through all the spots a curved line was drawn, which terminated at both ends of the ship in the water-line, and at first sight appeared to be a parabola, whose vertex was in the ⊕ section. To ascertain if it was really a parabolic line, two points were taken, the one in the section nearest to the stem, and the other at about the middle between the ⊕ section and the foremost section: besides the vertex there were then two abscissas and two ordinates to the same parabola, and the method was used to which I have given the name of the exponential calculation, to find the yet-unknown exponent; other ordinates were afterwards taken at the other sections, to which the lengths of the abscissas were calculated, and set off at their respective stations. In the same manner the part from the ⊕ section to the after section was determined, and a line drawn through all the spots. It was then seen, that in some ships, the line previously drawn according to the true sections of the ship, in many places does not agree with the latter regular line, and that in a drawing, the exponent of the sections forward is much less than that of the sections abaft. It should be observed, that the ⊕ section in this drawing is much before the middle. In some other draughts, the exponent of the after part is less than that of the fore part; and in others, the same parabola extended the whole length fore and aft; while the line drawn according to the areas of the sections on the quotients fell sometimes within and sometimes without the parabolic line; there were likewise other draughts in which the parabola and line of sections nearly coincided; and some in which the line of sections coincided so exactly with the parabolic line as if the line of sections had been drawn from it, which it really was not; those whose lines of sections agreed in this manner with the paraboba, were also the best ships in respect to good sailing: but in all the draughts, the parabola ended or cut the water-line a little within the extremities, especially forward.

With all the attention my other occupations permitted, I endeavoured in this manner to find, and ultimately hit upon, a short and safe method of making the drawings, not only of all ships of the line, but also of all other classes of large and small ships and vessels.

Immediately after I had completed this, I accidentally saw a little treatise which contained the experiments which were instituted in France by M.M. d'Alembert, Marquis de Condorcet, and l'Abbé Bussut; but they contain no other result than that the common theory was false, which says, that the resistance of the water is as the square of the sine of the angle of incidence, without bringing forward any other principle in its place. In perusing this treatise, it suggested itself to me, to also make an attempt on the same subject, which was afterwards done and inserted in the transactions of the Royal Academy of Sciences, in 1795.

In consequence of the results which I thence obtained, I have written this work, which is called "*A Theoretical Essay, &c.*" Now after having arrived as far as was necessary, both for ships of the line and frigates, I determined to proceed with what I had begun, before the interruption which would be occasioned by entering on the physical experiments.

40. As the method, which in connexion with these experiments is here used, to give ships their form abaft in the water, is difficult in the construction of the draughts of ships; I have been induced to give the before-mentioned short and safe method, which is much more simple and equally theoretical, although the relaxation-line is excluded; and further forward it will be found, by the comparison of these two methods of construction, which is the most advantageous. The principal difference consists in the form of the after sections, and to make this comparison correctly, the same kind of ship will be constructed by the relaxation-line as by the former method.

What will be correctly obtained by this method, is as follows, namely: when the displacement of the ship, the length of the upper water-line between the rabbets, the greatest breadth of the ship at this water-line, and the depth from the water-line to the upper edge of the rabbet of the keel in midships, are given, together with the situation of the centre of gravity of displacement longitudinally; then,

1. The area of the ⊕ section is known; 2, its situation before the middle of the length of the upper water-line, or before the centre of gravity of the displacement; 3, the area of every section both before and abaft the ⊕ section; and, 4,

certain other spots which direct the form of each section, so that its area may agree with that previously determined; and finally the determined displacement will be obtained, also the situation of its centre of gravity longitudinally, so that it may coincide with the situation designed for it. And as this method is founded on the parabola, it obtains the name of the parabolic method.[1]

41. To begin this construction, let the given displacement of the ship $= D$, the length of the construction water-line $= l$, and the breadth at the water-line $= B$.

Put $\frac{D}{l\,B} = t$, then the displacement of the ship is equal to that of a parallelopipedon, whose solid content $= l\,B\,t$, area of its horizontal plane $= l\,B$, and depth $= t$. The construction-element of the ship will be formed from this parallelopipedon, as in § 11.

Let $A\,B\,C\,D\,G\,E$, fig. 105, represent this parallelopipedon, $A\,B = l$, $H\,K = B$, and $B\,E = t$; then the area of its side $A\,B\,E\,F = l\,t$. As it is intended to form from this the construction-element of a ship, the segment $A\,B\,I\,A$ is to be formed, whose area will be = to the rectangle $A\,B\,E\,F\,A = l\,t$; and as this segment will be a parabola, put its exponent $= n$, and abscissa $H\,I = \mathbf{h}$; then is $\frac{n\,l\,\mathbf{h}}{n+1} = l\,t$, whose exponent $n = \frac{t}{\mathbf{h} - t}$.

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[1] It happens fortunately, that this line, which is in all respects so well adapted to the construction of the drawings of a ship, is the most simple of all regular lines. Its quadrature is easy, and the situation of its centre of gravity, both in the direction of its axis and its ordinate, is equally easy to be found. If the exponent is 1, it becomes a triangle; and if the exponent is infinitely great, it becomes a rectangle; thus the number of parabolas which can be constructed between a triangle and parabola, is infinite. If, for instance, the area of a water-line, section, or any figure whatever, is known, and its area is considered to be that of a parabola, then the relation between the fulness of the one water-line or section to the other may be found. In the same manner the fulness of one body may be compared with that of another; the use of which will be found further forward.

As $HI.\ HK$ will be = the area of the $\oplus$ section, and if the area is given, then is $\frac{\oplus}{B} = \mathbf{h} =$ the abscissa HI of the parabola, the whole parabolic area of which, $ABIA$, is known, which multiplied by the breadth B, gives the construction-element, whose solidity is equal to that of the displacement of the ship.

Draw the vertical lines, LQ, MP, NR, &c. whose lengths are known by the equation of the parabola; when these lengths are multiplied by the constant breadth $B = HK$ of the construction-element, then the area of every section is known.

42. To place the $\oplus$ section, so that the centre of gravity of the displacement may be at the point T, which is at a given distance from the middle point V of the length of the construction water-line, AB.

Suppose that there are two parabolas AI and BI on the line AB whose exponents are equal, and which have their vertex in I, and their common axis HI, but whose parameters are unequal, so that the ordinate HB is shorter than the ordinate HA.

Let V be the middle point of AB, and the common centre of gravity longitudinally of both the parabolic spaces AIH and BIH be in T; the question then is, at what place will the greatest breadth of this figure be, or the axis HI, so that their common centre of gravity may coincide in T.

Because the abscissa HI is common to both, their equation is $x = y^n$. As the distance of the centre of gravity of the parabolic area HBI or HAI from the axis HI is $= \frac{n+1}{2n+4}$ of the length of the ordinate, the centre of gravity of the longest from the axis HI is $= AH.\ \frac{n+1}{2n+4}$, and of the shortest is $= BH.\ \frac{n+1}{2n+4}$; and as their areas may be expressed by AH and BH, the moment of the longest from the axis $HI = \overline{AH}^2\ \frac{n+1}{2n+4}$, and of the shortest $= \overline{BH}^2\ \frac{n+1}{2n+4}$, and their common centre of gravity from H =

$\dfrac{\overline{\overline{AH}^2 - \overline{BH}^2}\ \dfrac{n+1}{2n+4}}{AB} = z = HT.$ Let $\dfrac{l}{2} = f$, then $AH = f + a + z$, and $BH = f - a - z$, which squared and subtracted gives, $\overline{AH}^2 - \overline{BH}^2 = 4fa + 4fz$, whence $\dfrac{\overline{4fa + 4fz}\,.\,\overline{n+1}}{\overline{2n+4}\,.\,2f} = z$, and therefore $z = a.\overline{n+1} = HT$; but the situation of the ⊕ section before the middle point V of the construction water-line is $= a.\overline{n+2}$.

43. As the area of all parabolas may be made equal to the area of the rectangle lt (§ 41) therefore, as $t : \mathbf{h} :: n : n + 1$, then will either the abscissa $\mathbf{h}$ or the exponent n be known, which may be taken from the drawings already made. Take a ship of 110 and of 66 guns, and let the abscissa **h** be required.

See Table No. 15.	110	66
Displacement $= D$	152875	88722
Length of the water-line $= L$	209,33	176,96
Decrease of length at both ends $= \frac{L}{84} = f$	2,492	2,107
Length of construction water-line $= l$	206,84	174,85
Greatest breadth at the water-line $= B$	56,27	48,46
Area of ⊕ section $=$ ⊕	1019,20	710,13
$\frac{D}{lB}$ = depth of rectangle $= t$	13,1348	10,4711
$\frac{\oplus}{B}$ = abscissa of parabola $= \mathbf{h}$	18,113	14,654

To find the value of **h** from these two ships by the exponential calculation; then $t_v : t_v :: \mathrm{h} : h$, whence the exponent $v = \dfrac{\log.\,\mathrm{h} - \log.\,h}{\log.\,\mathrm{t} - \log.\,t'}$, or $v = \dfrac{\log.\ 18{,}113 - \log.\ 14{,}654}{\log.\ 13{,}1348 - \log.\ 10{,}471} = 0{,}935$, and $\mathbf{h} = 1{,}6303\ .\ t^{0{,}935}$.

All the data are now obtained, which are necessary in forming the drawings, in the manner described in § 40 and 41, which are inserted in the following Table.

Table No. 33.

	110	94	80	74	66
Displacement to outside of timbers $= D$	152875	128297	107400	96422	88722
Length of construction water-line $= 5{,}18454\ D^{0{,}3088} = l$	206,84	195,94	185,48	179,40	174,85
Additional length at the ends $= \frac{l}{83} = f$	2,492	2,361	2,235	2,161	2,107
Additional length forward $= \frac{7}{10} f$	1,744	1,653	1,564	1,513	1,475
Additional length abaft $= \frac{3}{10} f$	0,748	0,708	0,671	0,648	0,632
Length of the whole water-line between the rabbets $= L$	209,33	198,30	187,71	181,56	176,96
Greatest breadth at the water-line, for three-deckers $= \frac{l^{0{,}9947}}{3{,}5734}$; and for two-deckers, $= \frac{l^{0{,}8393}}{1{,}5728} = B$	56,27	53,32	50,92	49,51	48,46
$\frac{D}{l\,B} = t$	13,1348	12,2800	11,3715	10,8558	10,4710
$1{,}6303 \cdot t^{0{,}985} = \mathbf{h}$	18,1130	17,0086	15,8291	15,1569	14,6540
Exponent of line of sections $= \frac{t}{\mathbf{h}-t} = n$	2,6385	2,5970	2,5510	2,5240	2,5032
Area of $\oplus$ section $= B\,\mathbf{h} = \oplus$	1019,22	906,90	806,02	750,42	710,13
Depth of construction $\oplus$ section $= 2{,}37402\ \mathbf{h}^{0{,}7647} = d$	21,750	20,729	19,620	18,980	18,497
Depth of the $\oplus$ section to the upper edge of the rabbet of keel $= 1{,}5032.\ d^{0{,}87} = q$	21,91	20,98	20,02	19,46	19,03

Table No. 33.—(*continued.*)

	110	94	80	74	66
Exponent of ⊕ section $= \frac{\oplus}{B\,d - \oplus} = m$	4,9796	4,5711	4,1756	3,9646	3,8132
Half-area of water section $= \frac{\overline{\frac{1}{2} B\,L}^{\,1,0461}}{1,7186} = \mathrm{W}$	5113,1	4567,2	4109,5	3854,1	3668,6
Exponent of water section $= \frac{\mathrm{W}}{\frac{1}{2} B\,L - \mathrm{W}} = r$	6,5882	6,3477	6,1372	6,0154	5,9257
Moment for three-deckers $= \frac{\overline{\frac{1}{2} B^3\,L}^{\,1,0259}}{2,9902}$, and for two-deckers $= \frac{\overline{\frac{1}{2} B^3\,L}^{\,1,0714}}{5,9551}$					
$= \int \frac{2}{3} y^3\,d\,x = p\,D$	2320500	1859900	1512300	1333400	1210800
From the centre of gravity of displacement to metacentre $= \frac{\int \frac{2}{3} y^3\,d\,x}{D} = p$	15,18	14,50	14,08	13,83	13,65
Exponent of displacement, calculated from the water-line downwards $= \frac{\frac{1}{2} D}{d\,\mathrm{W} - \frac{1}{2} D} = s$	2,1980	2,1015	1,9942	9332	1,8879
Centre of gravity of displacement below water-line $= \frac{\overline{\overline{s+1}\,.\,\overline{2s+1} + s\,.\,\overline{2s+4}}\,.\,d}{2\,.\,\overline{2s+1}\,.\,\overline{2s+4}} = g$	8,572	8,105	7,598	7,308	7,091

TABLE No. 33.—(*continued.*)

	110	94	80	74	66
Metacentre above water-line $= p - g = e$	6,608	6,395	6,482	6,522	6,559
Common centre of gravity of ship above water-line (§ 32, table No. 31) must be $= v$	2,800	2,384	2,220	2,230	2,240
Distance between metacentre and this centre of gravity $= a$	3,808	4,011	4,262	4,292	4,319
When all the ships with the same sails would be equally stiff (§ 34, table No. 31), a' must be	3,809	3,975	4,131	4,291	4,348
It has been assumed that the centre of gravity will be before the middle of the upper water-line, $L = \frac{L}{76}$	2,75	2,61	2,47	2,39	2,33
Middle of water-line l abaft the middle of water-line $L = 0,2 \cdot f$	0,50	0,47	0,45	0,43	0,42
When the centre of gravity is before the middle of water line $l =$ a	3,25	3,08	2,92	2,82	2,75
§ 42 Situation of ⊕ section before centre of gravity $= \mathrm{a} \cdot \overline{n+1}$	11,83	11,08	10,37	9,94	9,63
§ 42 Situation of ⊕ section before middle of construction water-line $l = \mathrm{a} \cdot \overline{n+2}$	15,08	14,16	13,29	12,76	12,38
$\frac{l}{2}$	103,42	97,97	92,74	89,70	87,42
From after-end of water-line l to ⊕	118,50	112,13	106,03	102,46	99,80
Distance between after-sections, $\frac{1}{10}$ part	11,850	11,213	10,603	10,246	9,980
From foremost-end of water-line l to ⊕	88,34	83,81	79,45	76,94	75,04
Distance between foremost sections, $\frac{1}{10}$ part	8,834	8,381	7,945	7,694	7,504
Height of battery	6,48	6,50	6,92	6,83	6,75

When the calculations of a ship are made according to this method, it must be examined if $\frac{n\,m\,l\,B\,d}{n+1\,.\,m+1} = \frac{r\,s\,L\,B\,d}{r+1\,.\,s+1}$ is = the displacement; if it is not so, there must be an error either in some exponent or dimension, because in the largest ship there cannot be a difference of above 3 or 4 feet in the displacement.

The true value of a', which is included between two lines in the table, is inserted for this reason: that if the value of a which is found, is considerably greater or less than a', then the quantity by which the half-breadth y must be increased or diminished, may be found by the method inserted in the table No. 31. In the example of a ship of 80 guns, it is found that $a-a'=4{,}262-4{,}131=0{,}131$ too much, and that the necessary decrease is obtained, by making the half-breadth y about one-tenth of an inch less, which is certainly inconsiderable. Suppose that the half-breadth should be less, by which the depth of the parallelopiped $\frac{D}{l\,B}$ is greater than before, then the abscissa $\mathbf{h}$ of the line of sections will be also greater in the same proportion, namely, as $t : t' :: \mathbf{h} : \mathbf{h}'$, nevertheless, the area of the ⊕ section and the exponent n of the line of sections are not altered.

The half-breadth may also be found by an easier method, in case any alteration is necessary.

The distance a' has been found to be $= \frac{75{,}33}{4\sqrt{D}}$ or all ships of the line; when the distance of the centre of gravity of the ship above the water-line, and the distance of the centre of gravity of the displacement below the water-line, are added to it, the length p is obtained, when $p\,D = \int \tfrac{2}{3}\,y^3\,d\,x$. From the two expressions inserted in the table, for finding $\int \tfrac{2}{3}\,y^3\,d\,x$, for three-deckers $\tfrac{1}{2}\,B = 3\sqrt{\frac{2{,}9902\,.\,p\,D}{L}}^{\frac{1}{1{,}0259}}$, and for two-deckers $\tfrac{1}{2}\,B = 3\sqrt{\frac{5{,}9551\,.\,p\,D}{L}}^{\frac{1}{1{,}0714}}$, according to which the drawings are made; and as the area of the ⊕ section and

the exponent n are constant, as just mentioned, the resistance is the same as before, whence all the ships sail equally fast, and with the same sails incline to the same angle.

In this manner a ship can be given according to circumstances the necessary stability, previously to beginning the drawings.

As the calculations which relate to the stability of a ship depend very much on the situation as to height of the centre of gravity of the ship, and as the situation of this centre should necessarily be known, although it has not hitherto been considered in a manner which could lead to the improvement of the science, it must now be seen, how necessary it is to find the means of obtaining this centre, and that for all ships and vessels sailing on a wind, it is one of the most important circumstances in the science of ship-building.

44. As the exponent of the parabola for the line of sections is the same both before and abaft the ⊕ section; if therefore, the distance both before and abaft the ⊕ section to the ends of the water-line l, is divided into an equal number of parts as in the foregoing table, then the distance between the divisions abaft the ⊕ section is greater than the distance between the divisions before it, whence the corresponding ordinates LQ, NR, of the line of sections at both ends, are of equal length; consequently, also the areas of the corresponding sections are equal, but of dissimilar figure: and it is from the greater spreading of the after sections, that the ship is sharper abaft than forward.

The ⊕ section is constructed in the same manner as before, see § 23 and tab. 21; but the upper end of the diagonal of construction at the after section, terminates in the same manner at the water-line and sternpost, as the diagonal of the sections forward.

For the construction of the sections, the ordinates C of the ribband-line are equally necessary now as before.

After the lengths of the ordinates h of the line of sections for all the sections, and the half-areas of the sections, are known and inserted in their columns for all the five ships, it is necessary to find a general rule, which will give the lengths of the ordinates C of the ribband-line from the water-line to the diagonal of construction at the 7th section, both forward and

abaft, for all ships of the line.—For finding these, ships of 110 and 66 guns are used.

$$\text{Forward}\begin{cases}110 & \begin{cases}C = 12{,}970\\ h = 11{,}045\end{cases}\\ 66 & \begin{cases}C = 103{,}00\\ h = 8{,}653\end{cases}\end{cases} \qquad \text{Abaft}\begin{cases}110 & \begin{cases}C = 12{,}300\\ h = 11{,}045\end{cases}\\ 66 & \begin{cases}C = 9{,}800\\ h = 8{,}653\end{cases}\end{cases}$$

At the 7th section forward

$$x = \frac{\log.\ 12{,}97 - \log.\ 10{,}3}{\log.\ 11{,}045 - \log.\ 8{,}653} = 0{,}9444$$

hence $C = 1{,}3421\ h^{0{,}9444}$

At the 7th section abaft

$$x = \frac{\log.\ 12{,}3 - \log.\ 9{,}8}{\log.\ 11{,}045 - \log.\ 8{,}653} = 0{,}9309$$

hence $C = 1{,}3147\ h^{0{,}9309}$

Hence the ordinates C of the ribband-line at the 7th section are obtained for the five ships.

		110	94	80	74	66
C at 7th section	forward	12,97	12,114	11,202	10,686	10,30
	abaft. ..	12,30	11,498	10,645	10,161	9,80

TABLE No. 34.

Calculations of the ordinates h of the line of sections (by the equation, $x = \frac{y^n}{p}$) whence the areas of the sections and the ordinates of the ribband-line.

For a ship of 110 guns.

Ordinate y	$\frac{y^{2,6385}}{24,017} = x$	Ordinates of the section-line $\mathbf{h} - x = h$	$\frac{1}{2}$ area of sections $= \frac{1}{2} b . h = 28,135 . h$	Ordinates C of the ribband-line. Forward.	Ordinates C of the ribband-line. Abaft.
10	18,113 = $\mathbf{h}$	0,000	0,00	—	—
9½	—	—	—	—	—
9	13,717	4,396	123,68	7,21	6,24
8	10,053	8,060	226,77	10,56	9,70
7	7,068	11,045	310,75	12,97	12,30
6	4,706	13,407	377,21	14,76	14,29
5	2,909	15,204	427,76	16,07	15,77
4	1,614	16,499	464,20	16,99	16,82
3	0,754	17,357	488,34	17,59	17,51
2	0,259	17,854	502,32	17,93	17,91
1	0,042	18,071	508,43	18,08	18,079
⊕	0,000	18,113	509,61	18,113	18,113

$C = \overline{1 - v} . h + v . \sqrt{\mathbf{h}\, h}$, whence $v = \frac{C - h}{\sqrt{\mathbf{h}\, h} - h}$ of 7th section

hence $v = 0,621$ forward | $v = 0,407$ abaft

$C = 0,379 . h + 0,621 \sqrt{\mathbf{h}\, h}$ | $C = 0,593 . h + 0,407 . \sqrt{\mathbf{h}\, h}$

For a ship of 94 guns.

Ordinate y	$\frac{y^{2,597}}{23,2451} = x$	Ordinates of the section-line $\mathbf{h} - x = h$	$\frac{1}{2}$ areas of sections $= \frac{1}{2} b . h = 26,66 . h$	Ordinates C of the ribband-line. Forward	Ordinates C of the ribband-line. Abaft.
10	17,009 = $\mathbf{h}$	0,000	0,00	—	—
9½	14,887	2,122	56,57	—	—
9	12,937	4,072	108,56	6,73	5,84
8	9,528	7,481	199,44	9,86	9,06
7	6,736	10,273	273,88	12,114	11,498
6	4,514	12,495	333,12	13,80	13,36
5	2,811	14,198	378,52	15,04	14,76
4	1,575	15,434	411,47	15,91	15,75
3	0,746	16,263	433,57	16,49	16,42
2	0,260	16,749	446,53	16,83	16,80
1	0,043	16,966	452,31	—	—
⊕	0,000	17,009	453,46	17,009	17,09

$v = 0,625$ forward | $v = 0,416$ abaft

$C = 0,375\, h + 0,625 \sqrt{\mathbf{h}\, h}$ | $C = 0,584\, h + 0,416 \sqrt{\mathbf{h}\, h}$

TABLE No. 34.—(*continued.*)

For a ship of 80 guns.

Ordinate y	$\frac{y^{2,551}}{22,4669}=x$	Ordinates of the section-line $\mathbf{h}-x=h$	$\frac{1}{2}$ area of sections $=\frac{1}{2}b.h=$ $25,46\,.\,h$	Ordinates C of the ribband-line. Forward.	Ordinates C of the ribband-line. Abaft.
10	15,829 = $\mathbf{h}$	0,000	0,00	—	—
$9\frac{1}{2}$	13,888	1,941	49,42	—	—
9	12,098	3,731	94,99	6,214	5,423
8	8,959	6,870	174,91	9,105	8,393
7	6,372	9,457	240,78	11,202	10,645
6	4,301	11,528	293,50	12,772	12,376
5	2,701	13,128	334,24	13,936	13,679
4	1,529	14,300	364,08	14,768	14,619
3	0,734	15,095	384,32	15,323	15,250
2	0,261	15,568	396,36	15,650	15,624
1	0,045	15,784	401,86	—	—
⊕	0,000	15,829	403,01	15,829	15,829

$v = 0,628$ forward; $C = 0,372\,h + 0,628\sqrt{\mathbf{h}\,h}$

$v = 0,428$ abaft; $C = 0,572\,h + 0,428\sqrt{\mathbf{h}\,h}$

For a ship of 74 guns.

Ordinate y	$\frac{y^{2,594}}{22,049}=x$	Ordinates of the section-line $\mathbf{h}-x=h$	$\frac{1}{2}$ area of sections $=\frac{1}{2}b.h=$ $24,755\,.\,h$	Ordinates C of the ribband-line. Forward.	Ordinates C of the ribband-line. Abaft.
10	15,157 = $\mathbf{h}$	0,000	0,00	—	—
$9\frac{1}{2}$	13,316	1,841	45,57	—	—
9	11,618	3,539	87,61	5,923	5,185
8	8,630	6,527	161,58	8,681	8,014
7	6,161	8,996	222,70	10,686	10,161
6	4,175	10,892	271,86	12,191	11,817
5	2,635	12,522	309,98	13,312	13,068
4	1,500	13,657	338,08	14,117	13,975
3	0,726	14,431	357,24	14,657	14,587
2	0,261	14,896	368,75	14,978	14,953
1	0,045	15,112	374,10	—	—
⊕	0,000	15,157	375,21	15,157	15,157

$v = 0,630$ forward; $C = 0,370\,h + 0,630\sqrt{\mathbf{h}\,h}$

$v = 0,435$ abaft; $C = 0,565\,h + 0,435\sqrt{\mathbf{h}\,h}$

TABLE No. 34.—(*continued.*)

For a ship of 66 guns.					
Ordinate y	$\frac{y^{3,5032}}{21,7392} = x$	Ordinates of the section-line $\mathbf{h} - x = h$	$\frac{1}{2}$ area of sections $= \frac{1}{2} b \,.\, h = 24,23 \,.\, h$	Ordinates C of the ribband-line. Forward.	Abaft.
10	14,654 = **h**	0,000	0,00	—	—
9½	12,892	1,762	42,69	—	—
9	11,257	1,397	82,31	5,71	5,01
8	8,382	6,272	151,97	8,36	7,73
7	6,001	8,653	209,66	10,30	9,80
6	4,080	10,574	256,21	11,76	11,40
5	2,585	12,069	292,43	12,84	12,61
4	1,479	13,175	319,23	13,63	13,49
3	0,720	13,934	337,62	14,16	14,09
2	0,261	14,393	348,74	14,47	14,45
1	0,046	14,608	353,98	—	—
⊕	0,000	14,654	355,07	14,65	14,65
$v = 0,631$ forward $C = 0,369 \,.\, h + 0,631 \,.\, \sqrt{\mathbf{h}\, h}$			$v = 0,44$ abaft $C = 0,56 \,.\, h + 0,44 \,.\, \sqrt{\mathbf{h}\, h}$		

Agreeably to the foregoing Tables No. 33 and 34, the drawings of the five ships of the line, Plates XI, XII, XIII, XIV, and XV, are constructed.—There are two plates to each ship, marked with the same number. The sheer-draughts are marked *A*, and the body-plans *B*. The measurements are then made from these drawings, and the results inserted in the following Table.

TABLE No. 35.

	110	94	80	74	66
Displacement......................	152854	128287	107390	96418	88714
Centre of gravity before the middle of the construction water-line l....	3,33	3,128	2,90	2,75	2,82
Half-area of upper water-section = W	5100	4560	4100	3848	3650
$\frac{\int \frac{2}{3} y^3 \, dx}{D} = p$..................	15,139	14,404	14,0	13,887	13,733
Centre of gravity of displacement below upper water-line = g.......	8,539	8,052	7,54	7,234	7,020
Metacentre above water-line = $p - g = e$......................	6,600	6,352	6,460	6,553	6,713

The only deviation from the proportions, which are inserted in tab. No. 33, which may be allowed, is in the exponent n of the line of sections, which is for a ship of 74 guns = 2,524, which might be reduced to 2,5 or 2,49, and in the same proportion for the other ships, by which they become something sharper at the extremities; and as the equation $n = \frac{t}{\mathbf{h} - t}$ is constant, the greater **h** is, the greater also is the area of the $\oplus$ section: unless some other term is altered, besides those in which are only the quantities n, **h** and $\oplus$.

45. Now when an acquaintance with this method of construction is obtained, and it is desired to examine the drawings of ships and vessels which have been built, without respect to the form of their $\oplus$ sections, the following explanation will be attended to.

To facilitate the measurements of the breadths of the water-lines, it is necessary to be furnished with such a scale as is described in § 30. Calculate the area either of every section found in the draught or of every other section, by which the displacement and situation of its centre of gravity longitudinally are known.—Divide the area of every section by the breadth of the $\oplus$ section, and set off the quotients from the water-line downwards on the corresponding sections, and through all the

spots thus found draw a curved line, which is called the line of sections; continue this line as well forward as abaft, in the direction of its curvature, to meet or intersect the water-line; the distance between these two intersections, is called the length of the water-line of construction.

Example: let the displacement of the vessel = D, the area of the ⊕ section = ⊕, its breadth at the water's surface = B, the length of the construction water-line = l, and the distance from the middle of this line to its centre of gravity = a.

Suppose that the line of sections just mentioned is a parabola, and let its exponent be = n, then the exponent of the line of sections $n = \frac{D}{l \oplus - D}$, and put $\frac{\oplus}{B} = \mathbf{h}$. As the situation of the ⊕ section of the drawing is not regarded, set off from the centre of gravity a distance $= a\,.\,\overline{n+1}$, which will be assumed as the situation of the ⊕ section. The distance from this station of the ⊕ section to the extremities of the construction water-line, as well forward as abaft, is divided into ten equal parts. Construct a parabola from the ⊕ section to one end of the line of sections, whose equation is $p\,x = y^n$. The longest ordinate y is = 10, when the abscissa x is = $\mathbf{h}$: when the abscissas x, which correspond to all the other ordinates, 9, 8, 7, &c. are subtracted from $\mathbf{h}$, then the co-ordinates or ordinates, if they be so called, are obtained, which are set off from the water-line both before and abaft the ⊕ section; and it will be found, that on a well-constructed ship's draught, the line of sections drawn on the same draught, will very nearly coincide with this parabola.

46. When the resistance of the water on the fore part of a ship of 74 guns, and the force of cohesion on the after part which opposes its course, are calculated, and the ticked line in fig. 79 is drawn accordingly, it is seen, that the force of cohesion abaft is increased, but the resistance forward is decreased: so that on the whole, the sum of the effects of the water to oppose a ship's course, is $\frac{1}{30}$ part less by the latter method of construction than by the former, where the direction of the relaxation-line is adopted. That this should be about

the proportion is evident, from a comparison of the exponents of the lines of sections, the former exponent m being $= 2{,}7468$, and the latter exponent n being $= 2{,}524$. The former exponent being so great, arises from this cause: As the relaxation-line must necessarily be applied to the after part of the ship, and as a diminution in the displacement cannot be allowed, it is necessary to make the fore body so much the fuller, by which the centre of gravity of the displacement comes about a foot further forward than in the latter method of construction, which certainly does not conduce to a ship's coming up well to the wind; and as this cannot be avoided in any other manner, than by increasing the depth of the upper part of the construction-element, and by a corresponding decrease in the depth of the lower part of the construction-element, by which the centre of gravity of displacement is removed further aft, and consequently, the exponent m of the line of sections forward is diminished; but as the diminution in the depth of the lower part of the construction element, causes that part of the after end of the ship, which takes the direction of the relaxation-line to be diminished, by which the force of cohesion is increased, little or nothing is gained by the application of the relaxation-line, especially in ships of the line; and as it is found, that it is impossible that it can be otherwise, and besides, as this method of construction is very difficult, the parabolic method of construction for ships of the line described in § 40 is adopted instead of it, as the simplest and most complete that can possibly be found, which will be treated on further forward.

As this alteration in the method of construction makes no difference either in the principal dimensions, the displacement, or the magnitude and form of the ⊕ section, and as the upper water-lines are very nearly equal; the stability is the same, and all the operations which are given for the former, are equally applicable to the latter method of construction. The sheer draughts, and the form of the sections above the height of breadth, are also the same. Consequently, the greater part of the fourth, fifth, and eighth chapters cannot be serviceable in this latter method of construction, but should nevertheless, in relation to both methods, as will hereafter be shown, be attentively considered.

CHAP. XIV.—*On the Figure called the* Accumulateur.

47. Now when the drawings of a ship of the line are made, the design and nature of the figure called the *Accumulateur* will be seen, which is mentioned in the note to § 16 in '*Künnedom af Linie-skepp.*'

Although it is not so complete as it might be, and in order to render it concise, no scale of the drawing, &c. is annexed to it (the properties of which may be obtained from the just-mentioned treatise on ship-building printed in 1775), yet not only the effect which the metacentre has on the stability may be plainly seen there, but also how much stability is lost during a voyage, by the diminution of the provisions and ammunition, &c. which the greater or less elevation of the metacentre correctly indicates. A rule is also obtained by this figure, for finding the height of the common centre of gravity of the ship and lading.

Fig. 106 is this *accumulateur*. The upper scale marks the cubic feet of water, by which the displacement to the outside of the timbers is found, at different depths.

The vertical scale shows the distances in feet of the water-lines, 2, 3, 4, &c. below the upper water-line. The line $A\,C$ is the water-line when the ship is completely armed. From A, where the first-mentioned scale commences, the line $A\,G$ is drawn perpendicular to $A\,C$. Draw the lines 2, 3, 4, &c. parallel to $A\,C$, at equal distances from one another, and the same as the water-lines on the parabolic body-plan of a ship of 74 guns, Plate XIV. *B*, which is used in calculating the displacement.

Set off by the upper scale the displacement between the 1st and 2nd water-line which is $= Q\,R$, and between the 1st and 3rd $= S\,T$, and so on for all the water-lines. Draw through the points A, T, F, the curved line $A\,T\,F$, then $Q\,R$ expresses the displacement between the 1st and 2nd water-line, and $R\,V$ the displacement below the 2nd water-line to the keel. $S\,T =$ the displacement between the 1st and 3rd water-line, and $T\,Z$ the displacement below the 3rd water-line to the keel.

Let $FG = AX$, which expresses the displacement $= D$; QR, ST, which express the displacement above the water-lines $= W$, then QR is $= W$, and $RV = D - W$; $ST = W$, and $TZ = D - W$, and so on. It is to be observed, that each quantity W has its separate value.

In order to clearly see how the metacentre moves as the ship rises higher out of the water by the diminution of the lading, draw the lines KL, MN, &c. parallel to the vertical line BE, at the same distance apart as the water-lines 1, 2, 3, &c. Let H, K, M, O, D, be the centre of gravity of the displacement for each quantity, $D - W$, and draw the line HMD, then the centres of gravity of the displaced volumes for all the diminished displacements $D - W$ lie in this line.

Divide $\int \frac{2}{3} y^3 \, dx$ for each water-line by its corresponding displacement $D - W$, and set off the quotients from H, K, M, &c. to ILN, &c., and draw the curved line $INPD$, then this line determines the situation of the metacentre for every water-line. Thus BI is $=$ the height of the metacentre above the water-line when the ship has its full lading or is armed; and if the ship is light, so that it floats at the 5th water-line, the metacentre rises a height $= xN$. Thus the curved line ILN is the locus of the metacentre.

If the common centre of gravity of the ship and lading, when it is armed, is in $r = 2{,}23$ feet above the water-line BC (see § 32), then rl is $=$ the distance between the centre of gravity of the ship and the metacentre.

Suppose that the ship is at sea and that all the provisions and ammunition are consumed. Suppose the centre of gravity of the bread and flour to be in t, of the powder and wadding in v, of the provisions in casks and of the brandy in w, of the shot in y, and of the coals in z. Suppose also that at another time, half of all these articles is consumed, then it will be seen by the following example how much the centre of gravity rises by the diminution of these weights.

What was inserted in tab. No. 10, § 9, and in the note to it, is to be observed: that the displacement of the ship is calculated on the supposition that one-fourth part of the provisions is consumed, so that it is the remaining three-fourths of the provisions which will be consumed during the voyage; also in

§ 6, tab. No. 5, that 25 round shot and the wadding for all the guns are lying on the deck, which weights are not included with those in the hold, which would be diminished during the voyage.

As the floating of the ship is in the proportion of these weights to the displacement taken to the outside of the planking, and as the displacement was calculated only to the outside of the timbers, in order to preserve the proportion, all the weights which would be consumed, must be diminished one-twentieth part; and these weights thus diminished are inserted in the following table.

Displacement to the outside of the timbers $= D = 96420$ cubic feet.		The whole.			The half.		
		Wt. in cubic feet.	Its centre of gr. below the centre of gr. of the ship, r.	Moment	Wt. in cubic feet.	Its centre of gr. below the centre of gr. of the ship, r.	Moment
t	Bread and flour	2552	1,23	3139	1276	0,23	293
v	Powder and wadding	973	9,00	8757	486	8,00	3888
w	Provisions in casks, brandy, &c.	1518	10,50	15939	759	9,50	7210
y	Cannon shot..............	2271	11,60	26344	1136	10,60	12042
z	Coals	729	15,50	11299	364	14,50	5278
	Total	8043		65478	4021		28711

$$\text{Hence } \frac{65478}{96420-8043} = 0{,}74 \text{ ft.; and } \frac{28711}{96420-4021} = 0{,}31 \text{ ft.}$$

Thus the common centre of gravity of the ship rises by the diminution of the whole weights 0,74 foot higher than it was before, and of half the weights, 0,31 foot. It was found from the cubic scale, that the ship in the first case, by the diminution of 8043 cubic feet in the displacement, rises 1,05 foot $= A g$, and by the diminution of 4021 cubic feet 0,51 foot $= A h$.

From r draw $r s$ parallel to $B C$, from the vertical line $B I$ set off $r b = 1{,}05$ foot, and $r a = 0{,}51$ foot, and draw $b a$, $a c$

parallel to $r\,l$. From b take $b\,f = 0,74$, and from a take $a\,e = 0,31$: then $f\,d$ is = the distance between the centre of gravity of the ship and the metacentre in the first case, and $e\,c$ = the distance between these centres in the latter case.

The distances, $r\,l$, $e\,c$, and $f\,d$, are = 4,475, 4,29, 3,98, and their corresponding displacements = 96420, 92399, 88377, hence the moments of stability are = 4,475 . 96420, 4,29 . 92399 and 3,98 . 88377 = 431479, 396392 and 351740.

It will be now seen how much sail it can carry, so that the inclination in action shall not exceed 7 degrees.

When all the provisions and ammunition are consumed, the displacement of the ship to the outside of the timbers = 96420 − 8043 = 88377 cubic feet, and when the planking is added to this quantity, the displacement Q = 93028 cubic feet, and as 3,98 = a, $a\,Q$ = 370251.

$$
\begin{array}{lcll}
a\,Q = 370251 & = & 5,5684968 & \\
\text{sin. } 7^\circ \ldots\ldots & = & 9,0858949 & \\
\hline
 & & 14,6543913 & \\
\text{rad.} \ldots\ldots & = & 10 & \\
\hline
 & & 4,6543913 & = 45122,3 \\
\hline
\cos. 7^\circ \ldots\ldots & = & 9,9967507 & \\
b\,P = 18879 & = & 4,2759790 & \\
\hline
 & & 14,2727297 & \\
\text{rad.} \ldots\ldots & = & 10 & \\
\hline
 & & 4,2727297 & = 18738,3 \\
 & & & \overline{26384,0}
\end{array}
$$

26384,0 = moment of the power of the sails, M. Thus it will be found by reference to the table in § 16, on the area of sails of ships of the line, that when this ship takes in its top-gallantsails, it will not under these circumstances incline more than 7 degrees. But if this ship were according to the com-

mon method of construction, so that as it lightened and rose higher out of the water, the metacentre did not at the same time rise in the ship, it would be necessary to take in nearly a whole reef in each of the topsails, in order that the inclination might not exceed 7 degrees.

The following observation will be made on the diminution of the provisions during a voyage.

As it is found, that when the weights which are situated below the centre of gravity of the ship are taken away this centre rises higher in the ship than before, and as it hence comes nearer to the metacentre, the moment of the stability of the ship is diminished; and therefore the inclination when close-hauled is greater than before; and if the inclination is not increased, the area of the sail must be diminished: thus to avoid the inconvenience of a greater inclination, the ship loses in sailing fast. The state of the case is such, and it can only in some degree be obviated in this manner, namely, that all the weights which are not diminished during a voyage, may be placed low in the ship, and those weights which are diminished during a voyage may be placed as high in the ship as they conveniently can; but this circumstance has not been attended to sufficiently. One ship has its anchors stowed on the orlop, and the bread and flour in the hold; in another it has been found more convenient to have the anchors in the hold, and the bread and flour on the orlop deck; and the latter method is right, because the ship during a voyage, when all the bread and flour are consumed, does not lose so much stability as when they are placed below the orlop in the hold.

48. As it is impossible to construct a drawing of a ship of the line which can be depended on, without having the situation of its centre of gravity known, a practical method of finding it will now be given; but previously, the following problem must be solved.

Let there be a drawing of a ship, in which the situation of the centre of gravity is known as to height, and suppose that this ship is grounded and that the water gradually leaves it: then the question is, how much the surface of the water may be lowered on the ship, so that it may be balanced between remaining upright and inclining on either side.

Let therefore AEB, fig. 107, be the transverse section of a ship floating on the water, CD its water-line, E the lower edge of the keel, F its centre gravity when armed, and G its metacentre.—Suppose that the water has fallen, that the keel E is grounded, and that the water's surface has sunk some distance below the water-line of the ship CD.

Let the displacement or weight of the ship $= D$, and the weight of the water diminished below the water-line of the ship $=$ W; then the quantity of water, which still supports the ship $= D -$W; consequently the moment of the force of the water to keep the ship upright $= \overline{D-\mathrm{W}} \,.\, FG$, and the moment of the force to incline or upset the ship $= W \,.\, FE$. Hence, when $\overline{D-W} \,.\, FG = W \,.\, FE$, the ship will balance between remaining upright and inclining to either side.

When $W = 0$, the moment of the force which causes the inclination $= 0$, and when $W = D$, the force which keeps the ship upright $= 0$. The quantity D and the distance FE are constant; and as the quantity W and the distance FG will vary for every depression of the water-line HI; the solution of this problem would be very difficult; but by the use of the *accumulateur*, it is very easy, as appears in the following manner.

Take the same ship of 74 guns completely armed, for which the *accumulateur* is made.

From the lower edge of the keel to the water-line $1 = YB = 21{,}42$, fig. 106; from the same water-line to the centre of gravity of the ship $r = 2{,}23 = Br$, which quantities added together $= 23{,}65 = h = Yr$. From the centre of gravity of the ship r to the metacentre $I = rI = a = 4{,}475$; D $=$ 96420. In the equation $\overline{D-W} \,.\, FG = W \,.\, FE$, $FG = a$ and $FE = h$, hence $\overline{D-W} \,.\, a = Wh$.

To render this clear the whole is inserted in the following Table.

The displacement is taken on the greater scale.		W	$D-W$	$a=r\ l$ $\pi\ \epsilon$ $s\ L$	Moment of force which keeps the ship upright $\frac{\overline{D-W}.a}{D}$	Moment of force which tends to upset the ship $\frac{h\ W}{D}$
Between 1st and 2nd water-line..		17794	—	—	—	—
Between 1st and 3rd		34694	—	—	—	—
Below 1st water-line		—	96420	—	—	—
Below 2nd		—	78626	—	—	—
Below 3rd......................		—	61726	—	—	—
Distance between centre of gravity and metacentre	1st water-line $= r\ l$	—	—	4,475	4,475	0,000
	2nd........ $= \pi\ \epsilon$	—	—	5,080	4,143	4,364
	3rd........ $= s\ L$	—	—	5,920	3,797	8,510

The moment $\overline{D-W}\ .\ a$, and $h\ W$, have been divided by D, only in order to obtain a convenient length in the construction.

From the vertical line $B\ E$, set off $B\ h = 4{,}475$, $i\ k = 4{,}143$, and $l\ m = 3{,}7973$; through these spots, draw the line $h\ k\ m$, then the force which keeps the ship upright is always in this line. From the same vertical line $B\ E$, set off $i\ n = 4{,}364$, and $l\ p = 8{,}51$. Through these points draw the line $B\ n\ p$, then the force which tends to incline the ship is always in this line; consequently, where these two lines cut each other as at o, these two forces are in equilibrium with each other, so that the ship stands on its keel and is balanced, between remaining upright and inclining on either side, and this point o is 2,265 feet below the upper water-line, which was the distance to be found.

As the value of $a + h$ in the equation is now known; if h is taken greater, the distances $i\ n$ and $l\ p$ are greater: and as a is therefore less, $B\ h$, $i\ k$, and $l\ m$, are also less, hence the point of intersection o comes higher than before; and conversely, if h is taken less, a is greater, and the point o comes lower than before: it is therefore found, that when the centre of gravity of the ship is higher, it does not allow of so great a decrease of the water before it inclines, as when the centre of gravity is lower down.

49. By means of the equation $\overline{D - W} \cdot a = W h$, the situation of the centre of gravity of the ship as to height can be easily found, when it is placed in a dock, in the following manner:

When a ship is brought into dock, its water-line is marked by nails driven in at the extremities and at the sides in midships, and when by the lowering of the water in the dock the ship takes a very small inclination, the new water-line is marked on each side in midships; now when the distance between these marks and those at first made on each side are measured, added together, and half their sum is taken, the distance which the water's surface has sunk below the height of the water-line when the ship came into dock is obtained, and the height of the water's surface, at which the ship began to balance between standing upright and inclining to one side.

During the observation of the inclination and its being marked, the pumping is suspended for a few minutes, in order to adjust the convenient height of the water by letting it into or out of the dock. When the experiment is made, a little water is let into the dock, that the ship may be supported and stand upright.

It is requisite to have the drawings by which the ship was built, in this case, as it was before, from which the displacement and length may be known, which are necessary to the solution of the problem.

The method of finding the situation of the centre of gravity as to height from the observed depression of the water, is as follows:

The ship may have any draught of water, but the blocks must be laid to the declivity agreeing with the difference of the draught of water of the ship. If it is completely armed, wholly or partly rigged, with or without masts, with more or less ballast, it makes no difference in what situation the ship is, because the centre which is found is the common centre of gravity of the ship and every thing connected with it.

The equation on which the solution of this problem depends, is $\overline{D - W} \cdot a = h W$; and as a = the distance from the metacentre to the centre of gravity, and h = the distance from the under side of the keel to the centre of gravity, are not known, but the sum of both these quantities together, which is = distance from the under side of the keel to the meta-

centre, can be found from the drawing of the ship; put therefore the distance from the under side of the keel to the metacentre $= k$, and the distance from the metacentre to the centre of gravity $= x$, then h is $= k - x$; thus $\overline{D - W} \cdot x = \overline{k - x} \cdot W$, hence $x = \frac{k\,W}{D}$; also to find k, W, and D, draw on the sheer-draught of the ship the two water-lines parallel to each other, the one the water-line of the ship when it came nto dock, and the other the water-line when grounded on the blocks and balanced. The displacement is then found below the upper of the two water-lines, which is put $= D$, and the displacement below the lower water-line, which subtracted from D, is $= W$. Find the centre of gravity of the displacement below the lower water-line, and the value of $\int \frac{2}{3}\, y^3\, d\,x$ at this water-line, and divide this quantity by its displacement; the quotient is = the distance from the centre of gravity of the displacement to the metacentre.

The distance from the lower side of the keel to this metacentre is then $= k$; thus all the three quantities k, W, and D, are known, and therefore x is known.

To give another example, applied to a less depth, a separate drawing should be made; it may therefore be supposed that this experiment as well as the former is made with the ship when armed; the depression of the water on the side of the ship is then = 2,265 feet = the distance o below the upper water-line, agreeably to which the ticked water-line $o\ q$ is drawn.

Take 2,265 feet, and apply this distance from the vertical line $H\,I = B\,\lambda$, from λ draw the line $\lambda\,\psi$ parallel to $H\,I$, then ψ is the metacentre for the water-line $q\ o$, consequently the distance $Y\,\psi = k = 28{,}7$ feet; and when the distance $q\,\theta$ is applied on the scale of the displacement, the quantity W is found to be = 16965,8 cubic feet, and as the whole displacement D = 96420 cubic feet, then $x = \frac{28{,}7\ .\ 16965{,}8}{96420} = 5{,}05 = \psi\,\phi$; and as the distance $\lambda\,\psi$ is = 7,28 feet, then 7,28 — 5,05 = 2,23 feet, which is the distance the centre of gravity is above the first water-line.

Such an experiment can conveniently be made in a dock

which is emptied by pumping, but not in a dock in which the water falls and rises by the ebb and flow of the tide.

Thus we have two practical methods of finding the situation of the centre of gravity of a ship: and it may be seen from what has been said in § 32, 35, and 43, that without having this centre known, it is impossible to construct the drawings of ships or vessels which may be depended on, especially of those which are armed. Consequently, in all drawings, especially those of ships of war and armed vessels, of every class, the situation of the centre of gravity and metacentre should be set off, in order to ensure their safety by a suitable and sufficient stability: and it should not hereafter be allowed to build ships and vessels by guess, or without having their stability known.

Chap. XV.—*On Frigates.*

50. A fleet must necessarily have frigates, not only to repeat signals, but also to obtain intelligence.—A nation must also have frigates to convoy merchant ships during war, and for other occasional services; thus their number and magnitude cannot be constant.

Their magnitude is expressed in the same manner as for ships of the line; namely, by the number of guns. The largest class carry from 44 to 40 guns, some fewer, and the smallest carry from 16 to 14 guns. Those vessels which carry a smaller number of guns have two masts, as snows and brigs.

Frigates have properly not more than one battery.—On this battery the larger frigates carry guns of the same weight of metal as two-decked ships on the second battery. The smallest frigates carry 12 and 8-pounders.

In the larger frigates there are not more than 13 guns on a side on the battery,[1] the rest are carried on the quarterdeck

[1] The same principle is followed here as for ships of the line; namely, the carrying heavy guns. A frigate which carries thirty 18-pounders on the deck requires a greater length than I have given to the frigate of forty guns, which carries twenty-six 24-pounders; the effect of the former is as 15.18, and of the latter as 13.24; that is, as 270 to 212; and when the men at the guns are included, it will be found that the frigate with twenty-six 24-pounders is more than 30 per cent. more powerful than that with thirty 18-pounders.

and forecastle, or on a whole deck which forms the quarter-deck and forecastle. The smaller frigates of from 20 to 16 guns carry their whole force on the same deck.

The larger frigates carry provisions for as long a time as ships of the line, but the smaller for a shorter time. The larger frigates should have a higher battery than ships of the line, not only for this reason, that as frigates have only one battery, they may be able to use it in a high sea—(When a ship of the line cannot open its lower-deck ports, it can always use its second battery, which is much higher than a frigate's battery)—but also for another reason, that as there must always be a clear ship, the whole of the crew will be lodged on the orlop deck, consequently all the provisions, cables, stores, &c., must necessarily be placed on platforms laid in the hold; thus the orlop must come as much higher as is necessary.

Respecting the sails, it may be concluded from what has been said, that a line of battle is never formed of frigates as it is of ships of the line; but that each frigate sails as well as possible: consequently the area of sail of each frigate is proportioned to its stability, by which the larger frigates sail faster than the smaller: thus their construction is not so difficult as that of ships of the line, all of which, whether larger or smaller, should, with the same sails set, sail equally well.

From all this it must be concluded, that it is easier to obtain a number of the best frigates than of ships of the line, because in the former most regard is paid to good sailing; that every frigate, *separately* or by itself, possesses the best possible qualities; whereas ships of the line must, *in common with others*, possess them, so that one ship may not excel another in sailing well and in stability.

It was said, that the largest class of frigates carry from 44 to 40 guns; but the reason that those of 40 guns are so commonly used must be, that they are of a size to manœuvre more readily, and at the same time carry a powerful armament, which can be worked without much difficulty, and are adapted for all seas.

As a double frigate has already been drawn by the application of the relaxation-line, three other frigates will be constructed by the same method, whose armament will be 40, 32, and 20 guns. The principal elements required for these three frigates are inserted in the following Table.

Table No. 36.

	40	32	20
Displacement $= D$	46480	27932	20462
Length of construction w. line $= 55{,}33 . \overline{D}^{0{,}34014} = l$	151,49	127,39	114,60
Increase forward	1,27	1,07	0,96
Increase abaft	0,44	0,58	0,62
Whole length of the water-line $= L$	153,20	129,04	116,18
$\frac{l^2}{19{,}8394} = A$	1156,22	817,98	661,97
$\frac{D}{A}$ = greatest breadth at the water-line $= B$ ..	40,20	34,16	30,92
$\frac{l}{13{,}5812} = \mathbf{h}$	11,154	9,38	8,438
Area of the ⊕ section $= B\,\mathbf{h} =$ ⊕	224,20	160,16	13 41
Centre of gravity before the middle of the construction water-line $l = \frac{l}{40{,}97}$	3,225	2,712	2,440
Depth of the ⊕ section of construction	14,832	12,590	11, 88
Depth of the ⊕ section to the keel	15,26	12,91	11,78
Distance between the two ⊕ sections	9,258	7,786	7,00
Distance between the sections abaft	7,638	6,423	5,778
Distance between the sections forward	6,585	5,537	4,982
In the ⊕ section of construction $b = \frac{\frac{1}{2} B^{0{,}916}}{1{,}3737} = b$	11,37	9,79	8,94
$\frac{b^{0{,}914}}{2{,}507} = d$ ..	3,68	3,21	2,95
$\frac{b}{3{,}176} = m$	3,58	3,08	2,81
$\frac{\overline{\frac{1}{2} B - b \,.\, h}^{0{,}428}}{1{,}6895} = w$	4,20	3,61	3,29
b, d, m, and w, represent the same quantities as in the construction of the ⊕ section of the ship of the line.			

The following Tables give the ordinates h of the line of sections, and thence the areas of the sections. Also the ordinates C of the ribband line for the fore-body, but the ordinates C of the ribband line for the after-body are equal to the ordinates h of the line of sections. The ordinates h of the line of sections of the after-body are taken in the same proportion to $\mathbf{h}$ of the ⊕ section as the ordinates which are found in the Table No. 14, Chap. V., are to $\mathbf{h}$ in its ⊕ section.

Table No. 37.

FRIGATE OF 40 GUNS.

	After-body.		Fore-body.				
	h	Areas of sections $\frac{1}{2} B \cdot h$	y	$\frac{y^{2,2383}}{15,52} = x$	$\mathbf{h} - x = h$	Areas of sections $\frac{1}{2} B \cdot h$	Ordinates C of the ribband-line
⊕	11,154	224,20	10	11,154	0,000	0,00	0,00
1	11,056	222,23	9	8,811	2,343	47,09	4,40
2	10,807	217,23	8	6,769	4,385	88,14	6,32
3	10,246	205,95	7	5,020	6,134	123,30	7,72
4	9,304	187,01	6	3,563	7,591	152,60	8,79
5	8,012	161,04	5	2,364	8,790	176,68	9,61
6	6,517	131,00	4	1,435	9,719	195,36	10,23
7	4,904	98,57	3	0,753	10,401	209,06	10,67
8	3,269	65,71	2	0,304	10,850	218,09	10,96
9	1,635	32,86	1	0,064	11,090	222,91	—
10	—	—	⊕	0,000	11,154	224,20	11,154

At the 7th section $z = \frac{x}{3,165} = 1,586.$

whence $h + z = 7,72 = C, \overline{1 - v} \cdot h$

$+ v \sqrt{\mathbf{h}\, h} = C,\ v = \frac{C - h}{\sqrt{\mathbf{h}\, h} - h} = 0,742,$

whence $0,258\, h + 0,742 \sqrt{\mathbf{h}\, h} = C$

for all the sections.

Table No. 37.—(*continued.*)

FRIGATE OF 32 GUNS.								
After-body.			Fore-body.					
	h	Areas of sections $\frac{1}{2} B . h$	y	$\frac{y^{2,2383}}{18,454} = x$	$\mathbf{h} - x = h$	Areas of sections $\frac{1}{2} B . h$	Ordinates C of the riband-line	
⊕	9,380	160,16	10	9,380	0,000	0,00	0,00	
1	9,297	158,75	9	7,409	1,971	33,65	3,60	
2	9,088	155,19	8	5,692	3,688	62,97	5,22	At the 7th section $z = \frac{x}{3,351} = 1,26$,
3	8,616	147,12	7	4,222	5,158	88,07	6,42	whence $h + z = 6,420 = C$; $\overline{1 - v} . h$
4	7,824	133,60	6	2,990	6,390	109,11	7,34	$+ v . \sqrt{\mathbf{h}\, h} = C$, $v = \frac{C - h}{\sqrt{\mathbf{h}\, h} - h} = 0,7008$,
5	6,738	115,05	5	1,988	7,392	126,22	8,05	
6	5,480	93,57	4	1,206	8,174	139,57	8,58	whence $0,2992 . h + 0,7008 . \sqrt{\mathbf{h}\, h} = C$
7	4,124	70,42	3	0,634	8,746	149,34	8,96	for all the sections.
8	2,749	46,94	2	0,256	9,124	155,79	9,21	
9	1,375	23,47	1	0,054	9,326	159,24	—	
10	0,000	—	⊕	0,000	9,380	160,16	9,38	

TABLE No 37.—(*continued.*)

FRIGATE OF 20 GUNS.							
After-body.			Fore-body.				
	h	Areas of sections $\frac{1}{2} B . h$	y	$\frac{y^{2,2383}}{20,522} = x$	$\mathbf{h} - x = h$	Areas of sections $\frac{1}{2} B . h$	Ordinates C of the riband-line
⊕	8,438	130,41	10	8,438	0,000	0,00	0,00
1	8,364	129,26	9	6,663	1,775	27,43	3,19
2	8,176	126,36	8	5,119	3,319	51,29	4,65
3	7,751	119,79	7	3,796	4,642	71,74	5,73
4	7,038	108,78	6	2,690	5,748	88,84	6,57
5	6,062	93,68	5	1,788	6,650	102,78	7,22
6	4,930	76,19	4	1,085	7,353	113,64	7,71
7	3,710	57,33	3	0,570	7,868	121,60	8,06
8	2,473	38,22	2	0,230	8,208	126,86	8,28
9	1,237	19,11	1	0,049	8,389	129,65	—
10	—	—	⊕	0,000	8,438	130,41	8,44

At the 7th section $z = \frac{x}{3,49} = 1,088$, whence $h + z = 5,73 = C$; $\overline{1 - v} . h + v . \sqrt{\mathbf{h}\, h} = C$, $v = \frac{h - C}{\sqrt{\mathbf{h}\, h} - h} = 0,6745$, whence $0,3255\, h + 0,6745 . \sqrt{\mathbf{h}\, h} = C$ for all the sections.

The drawings which are constructed according to these calculations are found in Plates XVII, XVIII, and XIX. Each frigate has two plates with the same number. The sheer-draughts are marked *A*, and the body-plans *B*.

The measurements are then taken from these drawings, and their results inserted in the following Table.

TABLE No. 38.

	40	32	20
Displacement $= D$	46561	27961	20463
Centre of gravity before the middle of the water-line of construction $= l$	3,225	2,675	2,430
Ditto before middle of water-line $= L$	2,81	2,43	2,26
Half-area of upper water-line $= W$	2543,3	1812,	1471,6
$\int \frac{2}{3} y^3 \, dx$	566902	291118	193028
$\frac{\int \frac{2}{3} y^3 \, dx}{D} = p$	12,204	10,412	9,433
Centre of gravity of displacement below upper water-line	5,481	4,639	4,193
Metacentre above water-line	6,721	5,773	5,240

(*To be concluded in the next Number.*)

ART. XXXI.—*Dimensions of an American Merchant-Ship, and Calculations of the American* 36-*Gun Frigates.* Communicated by JOHN LENTHALL, Esq., Washington City.

(*To the Editors of the Papers on Naval Architecture.*)

GENTLEMEN, Washington City, March 25th, 1831.

HAVING obtained some of your valuable "Papers on Naval Architecture," and observing that mention is made of American merchant-ships, I have taken the liberty of sending the dimensions of a ship built in this country, which sails fast and is said to possess other good qualities.—Should this subject be resumed in any of your future numbers, the necessary calculations can easily be made from this draught.—I also inclose some calculations I have made on one of the 36-gun ships of the navy; and should these prove acceptable, I may avail my-

self of another opportunity to forward some more extensive details upon the sloops of 24 guns.[1] Very respectfully,

Messrs. W. Morgan and A. Creuze. JOHN LENTHALL.

Dimensions of a Merchant-ship built in 1824 (Packet between Philadelphia and New Orleans), *with particulars for forming her draught.*

Length between perpendiculars, 103 feet—Beam moulded, 27 feet—Depth to upper deck, 16 feet 6 inches—Height between decks, 6 feet 6 inches—Depth of keel and false keel, clear of bottom plank, 15 inches, or 1 foot 6 inches below base line—Draught of water when launched (bowsprit in): aft 8 feet 3 inches, and forward 7 feet.

Iron fastening	12.589 lbs.
Copper bolts	1.783
Composition	2.550
Total weight of fastening . .	16.922 lbs.

	ft.	in.
Deadwood	0	4
Throats of floors	1	2
Ceiling plank...............	0	3
Hold & height between decks	16	6
Upper-deck plank..........	0	3
Waist, including plank sheer	0	10
	19	4
Deduct spring of beam..	0	6
Height to top of plank sheer	18	10

	ft.	in.
Height of lower edge of wales at $\oplus$	10	8
Height of 6 wales at 8½ inches	4	3
5 strakes of bright work at 4½	1	10½
1 string.....................	0	8½
1 drift	0	5
1 drift	0	8
Plank sheer	0	3
Height from base line to top of plank sheer	18	10

Timber and room, 2 feet—Rake of post, 1 foot 6 inches—Height of cross seam up perpendicular, 15 feet 6½ inches—Distance of $\oplus$ from fore perpendicular, 41 feet—Distance of S from fore perpendicular, 3 feet—Distance of 30 from after perpendicular, 2 feet.

				ft.	in.
Height of first diagonal up middle line of body plan				7	6½
Ditto	second	ditto	ditto	13	10½
Ditto	third	ditto	ditto	16	8
Distance of first diagonal from middle line on base line				8	3½
Height of second diagonal up side line of body plan				2	6½
Ditto	third	ditto	ditto	9	5½

[1] We shall be happy to receive this; and shall be glad of similar information on the elements of any other ships composing the American navy.—ED.

Heights and Breadths of Frames, &c.

Frames.	After Perpendicular.	30	28	26	24	22	20	16	12	8	4	⊕	D	H	J	L	N	P	R	S	Fore Perpendicular.
	ft. in.	ft. in.	ft. in.	ft. in.	ft. in.	ft. in.	ft. in.	ft. in.	ft. in.	ft. in	ft. in.	ft. in.	ft. in.	ft. in.	ft. in.	ft. in.	ft. in.	ft. in.	ft. in.	ft. in.	ft. in.
Rising of Height of breadth above base line.......	15. 6½	14. 10	13. 11	13. 5	13. 1	12.11¼	12. 9	12. 6½	12. 4	12. 2½	12. 1¾	12. 1	12. 1½	12. 2½	12. 3½	12. 5	12. 7	12. 9¼	13. 1	13. 3½	13. 7¾
Rising of Top ht., or under side of Plank sheer ...	20. 3	20. 1½	19. 11	19. 8½	19. 6½	parallel to H. B. at 6 feet 6 inches.															
Half breadth of main breadth..	9. 8¾	10. 2	10. 10	11. 4¾	11. 9	12. 1½	12. 5½	12.10¼	13. 2½	13. 4½	13. 5½	13. 6	13. 5	13. 3½	13. 1½	12. 10	12. 2½	10.11½	8. 3¾	5. 11¾	—
Do. top height.....	9. 3	9. 7	parallel at 8 inches.									12. 10	12. 9½	12. 8½	12. 7	12. 5¼	12. 2	11. 7¾	10. 9	9. 11½	7. 3
Do. 1st diagonal. ..	—	—	2. 0½	3. 3	4. 4	5. 3¼	6. 1	7. 3½	8. 0	8. 5½	8. 7¾	8. 8½	8. 7½	8. 3¾	8. 0	7. 6½	6. 8½	5. 3	2. 9¼	1. 2	—
Do. 2d ditto.....	—	3. 6½	6. 4	8. 1½	9. 7	10. 9	11. 8½	13. 1	14. 0	14. 6½	14. 10	14. 11	14. 10	14. 5	13.11½	13. 2¾	12. 1	10. 2½	7. 2½	5. 0	—
Do. 3d ditto.....	—	9. 1	11. 4½	12. 6¼	13. 4½	14. 0½	14. 6½	15. 3½	15. 9½	16. 0½	16. 2½	16. 3	16. 2	15.11½	15. 8½	15. 2½	14. 4	12. 9¼	10. 0	7. 11	—

First perpendicular section from middle line, 2 feet 6 inches—Second, 5 feet—Third, 7 feet 6 inches—Fourth, 10 feet.

Height of Perpendicular Sections above Base Line.

FRAME.	30	28	26	24
	ft. in.	ft. in.	ft. in.	ft. in.
1st perpendicular section ..	11. 4½	7. 8¾	5. 6½	3. 11
2d ditto ditto ..	12. 11½	9. 11	7. 9½	6. 2
3rd ditto ditto ..	13. 9	11. 3½	9. 5	7. 10
4th ditto ditto ..	14. 8½	12. 11	11. 3	9. 9¼

	ft.	in.
Cant of Fashion piece crosses middle line of Half breadth plan, forward of after perpendicular	3	8
Ditto, ditto, after perpendicular, out from middle line	12	8
Height of knuckle of counter above base line . . .	16	10
Knuckle abaft perpendicular, at that height . . .	2	3
Middle line of Counter abaft perpendicular, at under side of plank sheer	3	6

Position of the Masts.

	ft.	in.
Centre of fore-mast abaft fore perpendicular, at under side of plank sheer	15	2
Centre of main-mast . . ditto . . . ditto . .	59	0
Centre of mizen-mast. . ditto . . ditto . .	85	2

Shape of Stem—Fore side of Rabbet

	ft.	in.
Falls into lower edge of rabbet of keel (3 inches below base line) abaft frame N	0	5
Abaft perpendicular at 3 feet above base line . . .	4	6
Ditto . . . . 6 feet ditto	2	4½
Ditto . . . . 9 feet ditto	1	1
Rises above base line on frame P	0	4½
Ditto . . ditto . . R	2	6½
Ditto . . ditto . . S	5	0
Crosses perpendicular above base line	12	9¾
Falls out at 20 feet above base line	1	5
Fore end of keel abaft perpendicular	9	0

Calculations on an American Frigate[1] *of* 36 *Guns.*

The keel, post, rudder, stem, and cutwater, are not included in the calculations, which are to the outside of the plank—by the 3rd rule of Atwood. (*Philosophical Transactions.*)—Port sill 6 feet above water-line.

Displacement, in cubic feet	72919.51
Ditto forward of ⊕	27983.17
Ditto abaft ⊕	44936.34
Ditto forward of centre of gravity of displacement	37364.97
Ditto abaft ditto ditto . .	35554.54
Ditto *above* a horizontal plane through centre of gravity of displacement . .	39159.7
Ditto *below* ditto ditto . .	33759.81
	Feet.
Side of cube of similar content with circumscribing rectangular parallelopiped	50.42
Ditto ditto with displacement . .	41.77
Displacement in proportion to a circumscribing rectangular parallelopiped	.5688
Coefficient of displacement having area of water-line	12.1553
Ditto ditto ditto midship frame	119.005
	Feet.
Centre of gravity of displacement abaft ⊕ . .	15.5
Ditto ditto forward of middle of length of w.-line	3.0
Ditto ditto below water-line	7.089
Ditto of solid forward of ⊕, forward of ⊕ .	24.48
Ditto ditto abaft ⊕ – abaft ditto .	40.25
Ditto of solid forward of centre of gravity of displacement, forward of the said centre . .	31.8
Ditto ditto abaft centre of gravity of displacement, abaft ditto	32.83

[1] The principal dimensions of the ship are omitted in this account of the elements of her construction; however, as we have the value of the exponents of the line of sections, and of the water-line, we are enabled to deduce, by means of Chapman's expressions for these elements, which were given in Art. XVIII Vol. I of this work, that the length of her construction water-line is 166.2 feet, and that her breadth at the water-line is 41.46 feet. In the same article we see that the length of the construction water-line of his Majesty's ship Endymion is 157 feet, and that her breadth is 41.9 feet. About 8 inches must be deducted from each of these dimensions in the American ship, to compare them with those of the Endymion, as the American dimensions are calculated to the outside of the plank, and those of the Endymion only to the outside of the timbers.—Eds.

Area of floating line . . . . sq. ft.	5998.96
Centre of gravity of floating line abaft centre of gravity of displacement	ft. 4.7
Area of greatest transverse section, or ⊕ . . sq. ft.	612.74
Centre of gravity of ditto below water-line ft.	7.7
Area of vertical longitudinal section . . . sq. ft.	3122.86
Height of metacentre above centre of gravity of displacement	ft. 10.32
Height of metacentre, for pitching, above centre of gravity of displacement	ft. 154.8
Exponent of water-line	6.7828
Exponent of displacement	1.888
Ditto line of sections	2.52225
Ditto midship section	3.6135
Solid immersed at an inclination of 10° feet cube	5028.59

Art. XXXII.—*An Attempt to point out that particular Form for a Ship of War which the present state of our knowledge of the Science of Naval Architecture would lead us to adopt as the best calculated for Fast Sailing.* By Mr. W. Henwood, of his Majesty's Dock-yard, Portsmouth.

It was stated in a former paper in this work, that "we are utterly unable to prove that any one modification of the form of a ship, within the limits usually observed, is more conducive to velocity than another." Recent consideration of this observation has induced a conclusion that some light may notwithstanding be thrown on the difficulty thus declared to exist in Naval Science, by an induction from the knowledge we already possess.

The true method of computing the stability of a ship, demonstrated by Atwood, in the Philosophical Transactions for 1798, was a most important acquisition to Naval Architecture. It has made that certain which before was uncertain. It has placed completely within our grasp, the means of preventing such mistakes in constructing ships, as were but too frequently committed during the last century; and no uncertainty need now be felt by a scientific constructor, whether a ship will have sufficient stability. The utility of Atwood's method is not confined to the circumstance of having enabled us to construct

ships with a proper degree of stability. It will appear, from what follows, also to have led, in some instances, to the adoption of that particular form, or at least an approximation to that form, for the bottom of a ship, which is not merely the best adapted for stability, but which the present state of our knowledge seems to lead us to believe, is of all forms best calculated for velocity. If this point can be clearly established, it must be admitted to be of considerable consequence, as it will sanction the observance of a uniform and systematic mode of construction for ships of war, and other ships built for fast sailing; and it will discountenance attempts of individuals, uninformed of the true nature and difficulties of the subject, to palm their preconceived and ill-founded conceits, or as it has frequently been denominated, their "observation and experience," on the credulity of the public.

As the intelligent writer of Art. 5, Vol. 2, of this work, has made a comparison of Atwood's method of computing the stability of a ship, with the metacentric method of Bouguer; which has led him to express an opinion to the disparagement of the former; it is proper to notice the oversight through which Mr. Wilson appears to have been led to entertain a sentiment at variance with that of most writers on the subject. Mr. Wilson states, that he and a gentleman of great mathematical attainments, undertook the task of finding the centres of gravity of two frigates, having the same elements, but very dissimilar in form; and they then computed the stabilities of these frigates, both by Atwood's, and by Bouguer's method. At 12° inclination, it was found, that according to the former method, one ship "had $\frac{1}{28}$ more stability than the metacentric method would give, and the other ship $\frac{1}{18}$ less;—making, between the two, a difference of $\frac{1}{11}$." Mr. Wilson then says, "as both ships must have the same total displacement, and as the above difference arises solely from the ship with the least calculated stability, having a smaller portion of displacement near the water-line than the other, it follows that she must have a greater portion at some other place, which place will be near the keel. This will cause the ballast and all that is in her hold to be placed lower, which will lower the centre of gravity of the ship so much that it will diminish the difference above

given almost to nothing." The oversight above referred to is in this last sentence. Mr. Wilson has stated, he found "the exact centres of gravity" of the frigates, each of them of course with "the ballast and all that is in her hold," placed as low as possible. How the ballast, &c. can be placed lower than it was situated when the position of the centre of gravity of the frigate in question was calculated, Mr. Wilson doubtless will not try to explain. Atwood's, which is demonstrably the correct method of computing stability, is shown, by Mr. Wilson's comparison, to be infinitely more valuable than the obsolete and fallacious method of Bouguer by the metacentre.

Atwood's method has proved incontrovertibly, that the most easy and advantageous way of obtaining stability, is by a large area of floatation, and great fulness between wind and water; or, which is the same thing, by keeping the centre of gravity of the displacement at as short a distance as possible below the water's surface. The old notion, long entertained by constructors of ships, that a flat floor gives stability, led them of course to increase the breadth of ships as much as possible at the floor; or at the greatest depth below the surface of the water. In conformity with Atwood's demonstration, ships are, or ought to be, for the sake of stability, made as broad as possible at and near the water's surface; and they must consequently be made less broad at the floor;—supposing the depth of the floor, or that of the keel, to remain unaltered. It will now be endeavoured to adduce as strict and satisfactory a proof as the nature of the subject admits, that in whatever manner the water around a ship in motion is driven ahead, dispersed laterally, or made to pass towards the stern, a great breadth at the depth of the floor is calculated to retard the motion of a ship more than an increase of breadth at and just below the water's surface.

When a ship is sailing, she causes an elevation of the surface of the water at the fore part, which must extend to a greater or less distance all round the bows in proportion to the quantity of fluid raised above the natural level of the sea. If a ship, 150 feet long, is moving at the rate of 10 knots, or about 15 feet a second, she passes over a space equal to half her length, and displaces a body of water equal to half her displacement in five seconds: such a body of water, displaced by the fore

part of a ship in so short a time, must cause a very considerable body of water to be maintained above its natural level round the fore part of the ship.

Neither the actual height nor the extent of this elevation of the water can of course be ascertained. Chapman has very absurdly supposed that ' unless the ship sails in smooth water, the elevation or depression (at the stern) of the fluid will be reduced to nothing, or to very little;" and he has accordingly assumed the elevation of the water forward to be only six inches, when the velocity of the ship is 20 feet a second. Chapman ought rather to have said, that when there is much sea, it is impossible to observe the height of the elevation of the water. Robison states in his "Mechanical Philosophy," he "has often looked into the water from the poop of a second-rate man-of-war when she was sailing 11 miles an hour, which is a velocity of 16 feet per second nearly, and he not only observed that the back of the rudder was naked for about two feet below the water-line, but also that the trough or wake made by the ship was filled up with water which was broken and foaming to a considerable depth, and to a considerable distance from the vessel."

The direct resistance of the water against a ship, would of itself tend to elevate the bow and to depress the stern; and the increase of buoyancy arising from the elevation of the fluid forward, and the diminution of buoyancy arising from the depression of the water abaft, must have the same tendency. And thus it must happen, that in proportion as the level of the sea round a ship in motion is changed from its natural coincidence with the horizon, in the same, or in probably a greater degree, will that section of a ship which is called the load-water section in her quiescent position in still water, become inclined to the horizon. The perpendicular height of the elevation of the water at the head of a ship, and the perpendicular depth of the depression at the stern, are therefore, in all probability, much greater than from mere observation we are apt to suppose; and accordingly, the quantity of fluid actually elevated above the natural level forward, as well as the depression abaft, must also, it is highly probable, be much greater than has usually been considered.

Again, as the only force which can or which does act to

cause the water elevated round the bow to move towards the stern, is that which arises from the difference of the heights at which the surface of the sea stands, afore and abaft the mid-ship-part of the ship, during the motion; and as it is certain a quantity of water equal, or nearly so, to half the displacement, must be driven ahead of the ship in so small a period of time as five seconds; and as from the commonly-observed length of a ship's wake, the time required for the restoration of the level of the sea abaft a ship is so great; it is considered we are justified in concluding that the level of the sea is raised to a very considerable distance round the fore part of a ship, and that a very large body of water must, as long as so rapid a motion of the ship continues, be kept elevated round the bow above the natural level of the sea. The resistance on the fore part of a ship, sailing at the rate of ten knots, may, in fact, be considered as the effort (if the term may be allowed) of the ship to remove a body of water nearly equal to half the displacement in five seconds; which body of water, or the greater part of it, must be raised above the natural level of the sea before it can find a way of escape into the wake of the vessel. Now, as the pressure of a fluid on any particle or point of a surface immersed in it, is always in proportion to the perpendicular depth below the surface, it appears to follow, that in proportion as the elevation of the water round the fore part of a ship above its natural level, is caused by a displacement more of the upper than of the deeper water,—as must be the case when a ship has a comparatively large area of floatation, and great fulness between wind and water;—the ship will meet with proportionately less resistance than if her form were of the opposite character, viz. a small area of floatation, and a very full and flat floor.

As this reasoning and conclusion will not perhaps be regarded as a full investigation and convincing proof of the point proposed for consideration, it is proper to examine a little minutely the question, whether we have good reason to admit as a principle in the resistance of fluids, that the resistance is greater at greater depths. This Dr. Robison, in his Mechanical Philosophy, vol. 2 p. 293, states, is a "point still much contested;" and, he says, "it is a received opinion by many

not accustomed to mathematical researches, that the resistance is greater in greater depths." That this should be the received opinion of such only as are not accustomed to mathematical researches, would appear to imply that mathematicians in general rest their opinions respecting such a question on the hypothetical assumptions adopted as the foundation of their investigation. Mathematicians however, it is supposed, would not be willing for a moment to admit that such is the case. The hypotheses adopted by Sir I. Newton, and others, concerning the nature of fluids, or the action of their particles, are altogether a different thing from the mathematical reasoning built upon such hypotheses. The latter is unimpeachable. The former, however agreeable they may appear to be with the observed phenomena of nature, are always liable to be rejected as absurd by a new discovery which may be made of their disagreement with well-ascertained facts.

It is accordingly asserted by Dr. Robison, in the same vol. page 342, that " a plane of 2 feet wide and 1 foot deep, when it is not completely immersed, will be more resisted than a plane 2 feet deep and 1 foot wide; for there will be an accumulation against both; and even if these were equal in height, the additional surface will be greatest in the widest body; and the elevation will be greater, because the lateral escape will be more difficult."

With respect to the reasons Dr. Robison has assigned why the height of the elevation of the fluid would be greater before the broad surface than before the deep one, that " the lateral escape would be more difficult;" it seems to have been overlooked that the circumstance of the water rising against the anterior surfaces of the planes, above the height at which it stands or follows against their posterior surfaces, must cause part of the fluid to escape underneath the planes; and it certainly would escape much more easily underneath the broad plane than underneath the deep one; as may be shown thus: Let the elevation before each plane be 1 inch, and the depression behind 1 inch. The escape of the water under the broad plane will be caused by the pressure of 13 inches depth of water acting against 11 inches: and that under the deep one will be produced by the pressure of 25 inches acting against

23 inches. This result would be similar whatever be the height of the elevation. It also appears Dr. Robison has merely asserted that the fluid accumulated before the broad surface would be greater in quantity than that before the deep one; whereas it is absolutely impossible we can know whether it is greater or not. We know the same quantity of fluid must be displaced and driven forward by equal surfaces, whether broad or deep, moving with equal velocities: and the elevation of the water must depend on the *quantity* displaced and driven ahead. It therefore appears the reasons Dr. Robison has given for the truth of his assertion respecting the resistances on those planes, are unsatisfactory.

It is well known, as has been stated, that the pressure sustained by any particle of a fluid, or any point of a surface immersed in it, is always in proportion to the perpendicular depth below the surface. This is proved by the experiment of making holes at different heights in the side of a vessel filled with water, so that the fluid may spout perpendicularly upward. It is found that wherever an orifice is made, the water rises nearly to the same height as the surface in the vessel; the defect of height being no more than what must be occasioned by the friction at the orifice, the resistance of the air, and the effect of gravity on the ascending column. The same is also manifest from several other experiments which might be mentioned.

To compare the pressures on two planes not completely immersed, but each having an area of 2 feet superficial under the water;—the immersed part of one being 2 feet broad and 1 foot deep, and that of the other being 2 feet deep and 1 foot broad;—we must, as Dr. Robison mentions, take into the account the pressure of the atmosphere. The weight or pressure of the asmosphere on an area of 2 feet, is about 4150lbs.; the pressure of the water on the broad plane is about 64lbs., and on the deep one 128lbs. The absolute pressures on these two planes will therefore be about 4214lbs. and 4278lbs. This is merely to show the actual difference of the pressures. Suppose these vertical planes to be moved horizontally in the water, so as to cause an elevation of the water before, and a depression behind them. The pressures on each, which, when the planes were at rest, were equal on both sides of each plane,

become now considerably modified. There is an increase of pressure on the anterior surfaces, and a diminution of pressure on the posterior. The whole of the water pressing against their anterior surfaces, must escape over the borders; and as it has been shown that part of it would escape under the planes, and more underneath the broader plane than underneath the deeper;—and as the mean depth of the border multiplied by its length, which may be taken as a sufficiently correct measure of the difficulty of escape of the fluid round each, is about twice as great in the deep plane as in the broad one;—there appears no reason to conclude, that the fluid would escape with more facility round the border of the deeper plane than round that of the broader one; but rather the reverse. And as we know the absolute pressure is greatest against the deepest surface when at rest; and must certainly be so also at the first instant, and every succeeding instant of the motion; we have reason to conclude, in opposition to Dr. Robison's assertion, that the resistance,—which is to be viewed as the effect of increased pressure against the planes, more than as the effect of impulse,—must be greater against the deep surface than against the broad one.

The result of this examination of the question concerning the greater resistance at greater depths, will, it is supposed, be considered a sufficient warrant to conclude, that a great breadth at the depth of the floor of a ship,—if the resistance depends at all, as without doubt it must, upon the form of the midship section,—is calculated to retard the motion of a ship more than an increase of breadth at and just below the water's surface. This conclusion, however, respecting the comparative degree of resistance which would be produced by the two distinct forms of ships above described, may be strengthened by a deduction from a well-known experiment.

It is related in page 257 vol. 1 of this work, to which the reader is referred for the more particular account, that M. Romme "had two bodies made, the one an exact model of l'Illustre, a French seventy-four, on a scale of an inch to a foot, making the length of the model about fourteen feet, and its breadth three feet eight inches; the other model had the same midship section, the same length, stem, and stern-post,

with the fore and after parts formed by straight lines drawn from the midship section to the stem and stern-post."

"The commissioners MM. le Chevalier de Borda, de Bory, and l'Abbe Bossut, who examined the account of the experiments of M. Romme, and made a report on them to the French Academy," stated, that M. Romme had compared the resistances on these two models at different draughts of water, repeating each experiment many times, and taking a mean result for the sale of precision. The result of these experiments was, that the two models, at equal draughts of water, and moved by the same weights, always met with the same resistance. M. Romme also, having cut the models in two equal parts, and having joined the fore end of the first with the after end of the second, and the fore end of the second with the after end of the first, found the two bodies always passed over the same space in the same time, whether they were moved by the stem or by the stern-post. The Commissioners also stated, as the result of their examination, after they had duly weighed all they considered could be advanced in opposition to the conclusions of M. Romme, that " at least it is very probable the fore bodies of ships may vary considerably, the midship section remaining always the same, without the resistance being sensibly altered." This conclusion, if just, shows that the direct resistance of a ship depends principally on the form of the midship section.

One of the objections which these Commissioners mentioned, and which they considered as " the most important, is the apparent disagreement between the results of these experiments, and the effect produced on ships at sea in their velocity, by increasing or diminishing the difference of their draught of water forward and abaft."

Now, it is thought the only philosophical way of disproving the truth of Romme's conclusions, is by making similar, and, if possible, more accurate experiments on equally large and similar bodies. The writer is not aware that this has been done, and is therefore disposed to regard Romme's conclusions as highly important. And with respect to the above objection of the three Commissioners, it is to be remembered, the good effect sometimes produced on ships at sea in their velocities, by increasing or diminishing the difference of their draughts of

water forward and abaft, does not, in all probability, arise from actual diminution of the resistance; but rather from an amelioration of some bad quality of the ship, as deep pitching or 'scending, which must always greatly retard the motion; or, from a beneficial change in the position of the mean direction of the resistance in relation to the position of the centre of effort of the sails. There is every reason to believe a ship is often thus improved in sailing without having the resistance of the water diminished. The result of Romme's experiments, that "the two models, having the same draught of water, and moved by the same weights, always experienced the same resistance," is not affected by the objections offered by the three Commissioners.

If we take two midship sections, equal in area, one with a rising, and the other a flat floor, and suppose them to be immersed vertically in water, and then to be moved with equal velocities; the resistance on the former would, in accordance with the foregoing reasoning, be certainly less than that of the latter. According to the conclusion of the three Commissioners, there may be a considerable difference in the forms of the fore bodies of ships, whose midship sections are similar and equal, without the resistance being sensibly different: and if this is the case, we should be ready to suppose there might also be a dissimilarity in the after bodies of ships, without the resistance being perceptibly unequal. This is, in effect, what Romme has concluded,—that with the same midship section, and same length of ship, the direct resistance would be the same, whatever form was given to the fore and after bodies. And if this is the fact, it necessarily follows the direct resistance of a ship with a rising floor, would be less than that of another ship with a flat floor; the areas of their midship sections, draught of water, displacement, and other elements, being alike precisely in both.

That particular form therefore, for a fast-sailing ship, which the present state of our knowledge would lead us to adopt as the best calculated for fast sailing, is that which is determined by making as large an area of floatation, and as much rise of floor, as can be admitted; or, in a word, it is that form in which the centre of gravity of displacement is at the least

possible distance below the water's surface. If this position cannot fairly be shown to be untenable, it will, as has been mentioned, sanction the observance of a uniform and systematic mode of construction for ships of war. A brief reference to matter of fact will conclude this subject.

The writer was at sea in the Champion, during the three experimental cruises of that ship with the Orestes and Pylades. He has no hesitation whatever in declaring that the Orestes was the fastest-sailing vessel of the three; and this is now probably the general conviction respecting those ships. Even those who may consider one of the others to have been a more weatherly ship, will, it is supposed, allow, that in sailing free the Orestes in general sailed the fastest. The displacement of the Orestes was less than that of the Champion, and more than that of the Pylades. If the resistance were equal at all depths, and the forms of the fore and after bodies of ships also a matter of indifference, the least body would have met with the least direct resistance. A small inequality which there might have been in the quantity of sail spread in these ships, when they were crowded with sail before the wind, is a circumstance which could not sensibly have affected their velocities. The faster sailing of the Orestes therefore must, it is considered, have been the result of other circumstances. So far as the resistance depends on the form of the midship section, that of the Orestes, which has its centre of gravity at the least depth below the water, would cause the direct resistance of the Orestes to be less than that of the others. But, in no respect, is there so palpable a distinction between the three vessels, as in the distances at which their centres of gravity of displacements are situated below the surface of the water; that of the Orestes being, as is stated on page 71 vol. 1 of this work, at much the least depth below the load-water section.

The draughts of those small vessels of war which have recently been produced by Professor Inman, would, it is believed, if compared with draughts of other similar ships, be found to possess the same characteristic peculiarity of form; though it is by no means certain they possess this distinction in the highest degree.

A decision of the question of a greater resistance at greater

depths, is of exceeding importance in the construction of the larger classes of ships of war. At the depth of the floor of such ships, the pressure of the water is very much greater than just below the surface;—in the proportion nearly of five to three. And as almost all of our larger ships have very flat floors, their resistance to motion in the water must be greater than it would be if they had been constructed with a rise of floor.

The Caledonia,[1] and some other ships in our navy, have been spoken of as ships, "which, for beauty, strength, stability, quick sailing, &c., have probably not their equals in the world." The forms of the bottoms of those ships however are of that description which it has been shown is not the best calculated for velocity. Those ships were undoubtedly the best which could be constructed at the period they were produced. A flat-floored ship, it was then supposed, not only by the English, but by the much-better-qualified French constructor, would give great stability. And perhaps it was also generally endeavoured to give a ship "a full round bow, to meet a head sea;" and a form which would "let the water she displaces pass freely aft, as nature has provided in the shape of fish and water-fowl;" and which would also "not be immersed too deep in the water." Constructors formerly, and many persons now, who are equally well satisfied with their own favourite opinions concerning ships' hulls, never agree in defining what is "a full round bow,"—what is "a form which would let the water pass freely aft," if it does pass aft;—and, what is "too deep." A great many persons have made melancholy mistakes in not giving enough displacement, so that ships when built have been immersed "too deep" in the water;—much deeper than their constructors were of "opinion" they would be. The fact is, "opinion" should be allowed to have nothing whatever to do with the matter. The displacement of a ship, the centres of gravity, the positions of the masts, the stability, and every other element in the construction, can be accurately determined, and adjusted with certainty of good effect; and if what has been advanced in this paper cannot be fairly and fully confuted, that form may also be given to a ship which will certainly meet with

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* See Papers on Naval Architecture, Art. 16, Vol. 2.

the least resistance from the water, and at the same time ensure the requisite degree of stability.

It appears to be universally admitted, that during the late war, our enemies' ships did in general beat ours on most points of sailing. We have, however, every reason to believe that our ships were equally well, if not much better managed or sailed than those of our enemies. It is also well known that the French as well as others did then possess much more knowledge of the theoretic principles of naval architecture than we did. To what therefore can the superiority of their ships be ascribed but to this circumstance? Can it be desirable that we should continue to go on in the old way of building ships according to the inexplicable dogmas of—what has been absurdly supposed a very valuable acquisition,—' observation and experience' without scientific knowledge, whilst we have the means and opportunity of removing a reproach so discreditable to us as the first maritime nation of the world,—of being merely unsuccessful imitators of French ships, or " rule of thumb," or quack constructors.

The grand desideratum in naval warfare is fast-sailing ships. If a ship sails so badly that she cannot in general be made to overtake an enemy of equal or of inferior force; nor escape from one with a decidedly more powerful armament than her own; she had certainly much better be converted into a merchant vessel, than be made use of for the important purposes of war. The system of razeeing, which it appears has been unavoidably resorted to in order that our ships of war may be able to cope with those of other nations with a fair chance of success, is the only alteration which could be made in many of the existing race of ships which would be likely to improve their sailing qualities. The reduction in height of the topsides of such ships as the 28-gun frigates, by the removal of their quarterdecks and forecastles with the guns and other weights thereon, will cause those ships to swim considerably lighter; and if their centres of gravity be situated lower, their stability will most likely be increased. It is to be expected that by a judicious stowage of such ships, and a proper adjustment of the quantity of sail to the stability when cut down, they will in most instances be made to sail faster, and be more effective as

vessels of war. The increase of their rate of sailing will in direct courses be a consequence of the large diminution of the displacement; and in oblique courses, the sailing will be improved both by this circumstance, and by the reduction in height of the topsides, causing the force of the wind impressed on the hull to have a less powerful effect to drive the ship to leeward. Due resistance to lee-way may always be procured by an increase of the depth of the keel.

There will however be a radical defect in our razeed ships, caused by the alteration of cutting them down, which cannot be remedied by any mode of stowing them; and through which, there is reason to believe, they will still be inferior in point of sailing to those ships of war of foreign nations of similar force constructed expressly to carry long and heavy guns. The forms of the bottoms of our razeed ships will still be of that description which it has been shown is not the best adapted for velocity.

A formidable obstacle to an extensive improvement of the larger classes of ships of war exists, it is considered, through the usual mode of forming their decks. Reflection on this subject led to the publication of a new mode of framing ships, combined with a mode of forming decks, in Art. 2, Vol. 2, of this work. The common way of constructing decks, is like that of forming the floors of a house. In both instances, beams of considerable depth are first laid across, and a flooring of deals is then fastened upon them. Such a method of making the floor of a house, is doubtless better than any other which could be devised; and the space lost between the beams, is of no consequence whatever. In a ship however, where every practicable means should be made use of to diminish the whole height or depth of the hull, the loss of the space between the beams of all the decks is of exceeding importance. The great proportion of the height of a large ship, by which the hull might be reduced by means of that plan of decks, makes it very desirable, in the opinion of several individuals fully competent to judge of the matter, to whom the writer has had an opportunity of fully explaining the plan as improved since its publication, that a trial should be made of it. The plan has, it is true, been disapproved by some. But it is one

thing to condemn a project in private: it is another to give it so much attention as to acquire a complete understanding of it, and then show a satisfactory reason for passing the condemnatory sentence.

One of the most remarkable alterations in ships hitherto suggested, is that of Captain Napier, in the last number of this work;—that our ships of the line should be formed with a lower deck like a frigate, and have the lower and main decks, and the quarter deck and forecastle, about four feet higher than the lower, middle, and upper decks of a first-rate respectively are at present above the water.

The object of this proposal is stated to be, that a ship's company should not live and sleep on a fighting deck, but on a lower deck, as in a frigate. How far such an arrangement may be considered desirable by naval officers in general, the writer does not know: but, of course, such an alteration in ships, if carried into effect, would prevent that very desirable improvement of the forms of our ships, by reducing them in depth, which it has been shown would render them faster sailers. It has often been thought that much more space is taken up on the orlop decks of ships of the line, by the magazine passages and store-rooms and cabins, than there is any real necessity for. As a large proportion of chain cables have been substituted for hempen, and stowed in the hold, so much space cannot it is conceived be requisite for the cable tiers. Some part of the orlop in a ship of the line might, it is believed, be appropriated for the accommodation of a considerable part of the crew.

It may also be proposed as a question for consideration, whether, for the sake of improving the sailing qualities of our frigates, by a reduction of the height of their hulls, it may not be desirable that a part of their lower decks should be for the purpose of depositing a portion of the stores usually placed in the hold. And perhaps it would be attended neither with serious disadvantage nor inconvenience, if part of a frigate's crew were to live and sleep on the upper deck; as is the case on the lower or gun deck of a ship of the line; and the remainder on that part of the lower deck which could be kept solely for that purpose. Instead of having the waist open, it might be as much closed in as the gun deck of a second-rate

is by the upper deck, and a frigate's crew would then be better off when living and sleeping on the upper deck than those of a corvette, and as well off as those of a ship of the line. Some such arrangement would furnish the means of greatly improving the sailing qualities of our frigates.

All that has been advanced has been with a view of drawing the attention of naval architects and other individuals interested in the subject, to a practicable, extensive, and certain improvement of our ships of war in point of sailing. The desirableness of effecting this, is beyond all question. The means of accomplishing so important an object, has hitherto eluded the search, not only of the merely practical ship-builder, but even of men of scientific attainments. If this "attempt to point out that particular form for a ship of war which the present state of our knowledge would lead us to adopt as the best calculated for fast sailing," has been altogether successful, we have henceforth a straightforward course to pursue. We must diminish the depth of the full part of the bottoms of ships as much as possible, so as to have as small, or rather as shallow a hold as the most economical stowage of each ship will admit. We must also increase the area of the load-water section, principally by an addition to the breadth, so as to ensure a sufficient degree of stability. The form of ships at the ends above water, would not of course be different from what it is at present. At each end, the curvature at and above the load-water section, would be limited by the circumstance of allowing the planking to be bent round the bow and stern with moderate facility. The centre of gravity of displacement must be placed as at present, or so that the ship may swim at the intended water-line: and the centres of gravity of the immersion and emersion, should also be brought in the same transverse plane,—that the ship may always roll round a longitudinal, and not round a diagonal axis. The form below water would not then, it is evident, be left, as it has hitherto been, to the discretion of the constructor. It would be determined altogether by the circumstance of its being necessary to place the centre of gravity of the displacement at the least possible distance below the surface of the water, in order to obtain the maximum of stability and the fastest rate of sailing.

ART. XXXIII.—*A Table, showing the difference by the Stern in the Draught of Water of several Ships of each Class in His Majesty's Navy, when the Ballast is Stowed, to facilitate its Stowage in Similar Ships; so that when they are fully equipped for Sea they may sail at a given Trim.* By Mr. HENRY CRADOCK, Naval Architect, in His Majesty's Dock-yard, Portsmouth.

THE immense labour of re-stowing the hold of a ship, and the great delay it sometimes occasions, are facts well known to every person at all conversant with naval affairs. It becomes, therefore, a matter of considerable importance, to be able, without having recourse to this expedient, to stow a ship in such a manner that she may sail at the trim which her constructor may consider the best, or which may have been found to be so by experience.

As the situations of the greater part of the weights that are put into a ship are unavoidably fixed by circumstances, this object can only be effected by a judicious disposition of those that are moveable; viz. the ballast, and a very inconsiderable part of the stores. Upon the position of the ballast, therefore, the trim of the ship principally depends.

Now since the ballast, to give stability, is always placed in the lowest part of the hold, and therefore below the whole of the water and stores, it is evident that no alteration of any consequence can be effected in its position without unstowing; or, as it is technically called, breaking up the hold. To avoid the trouble and delay which this occasions, it not unfrequently happens that those weights which can be the most easily removed are placed in that extremity of the ship which requires to be more deeply immersed. This arrangement is attended with such injurious consequences, that every possible care should be taken to avoid the necessity of resorting to it. But the evils arising from a ship being too much by the head or stern, are sometimes greater than those occasioned by such a mode of stowage. Hence appears the great importance of placing the ballast in such a position, that when all the weights are on board no alteration shall be necessary.

This may be calculated with great accuracy. For knowing the difference between the light draught of water, and that to which it may be proposed to bring the ship when fully equipped, the centre of gravity of this part of the displacement may be found. And if, through this point, a transverse vertical plane be supposed to pass, the ballast must be so placed that its moment from it, together with the moments from the same plane of all the other weights to be put on board, may be equal to nothing. But independently of these calculations being very laborious, they are of such a nature that they cannot be performed by those persons who are usually employed in the stowage of ships; from which consideration the following Table has been formed, which, if not strictly applicable to every case, will enable them to avoid making errors of any great consequence.

Since the relative fineness and form of different ships' bodies are in some degree shown by the light draughts of water, it has been thought advisable to insert them in the Table, that a more correct judgment may be formed, as to which of the ships mentioned in it approximates the most nearly to the one which it may be required to stow; and may therefore be taken as a guide by which we may ascertain, nearly, what alteration will be necessary to be made in her trim by the ballast, so that when fully equipped she may be brought down to the trim named in the last column. But if a different trim should be determined upon, a corresponding alteration must be made by means of the ballast; and which must be left to the judgment and experience of the person employed. This must also apply to the case in which the light draught of water of the ship to be stowed may not exactly agree with any that are named.

It is proper to state, that for the materials of which this Table is composed the writer is indebted to a gentleman who has been principally employed for a number of years past in stowing the ships of war that have been fitted out at Portsmouth. And as he has always paid great attention to the subject of stowage, and carefully noted the results, the accuracy of the Table may be relied on.

TABLE, *showing the Difference by the Stern of the Draught of Water, &c.*

SHIPS' NAMES.	Number of Guns.	Tonnage.	Quantity of Ballast.	Light Draught of Water. Forward.		Light Draught of Water. Aft.		Draught of water with ballast stowed, and lower masts and bowsprit stepped. Forward.		Draught of water with ballast stowed, and lower masts and bowsprit stepped. Aft.		REMARKS.	Difference by the stern of the light draught of water.		Difference by the stern of the draught of water with ballast stowed, and lower masts & bowsprit stepped.		Proposed difference by the stern when fully equipped for sea.	
			Tons.	Ft.	In.	Ft.	In.	Ft.	In.	Ft.	In.		Ft.	In.	Ft.	In.	Ft.	In.
FIRST RATES.																		
Boyne	104	2155	269	14	6	18	1	16	10	19	0	Bowsprit not stepped.	3	7	2	2	1	2
Queen Charlotte	108	2289	286	15	8	18	8	17	4	19	7	Unmasted.	3	0	2	3	1	0
SECOND RATES.																		
Asia	84	2289	228	14	10	19	10	16	3	20	10	Built of teak.	5	0	4	7	1	8
Bellerophon	80	2056	205	13	9	16	11	15	9	17	11		3	2	2	2	1	0
THIRD RATES.																		
Ajax	74	1761	178	12	11	17	5	14	6	17	11		4	6	3	5	1	6
Carnatic	74	1790	179	12	7	17	9	14	8	18	6		5	2	3	10	1	8
Marlborough	74	1754	175	13	11	18	9	15	1	18	3	Built of teak.	4	10	3	2	1	7
Pembroke	74	1758	176	12	10	17	10	14	6	18	4		5	0	3	10	1	8
Spartiate	76	1949	150	13	1	18	0	14	11	18	3		4	11	3	4	1	8
Sultan	74	1751	175	13	2	18	0	15	0	18	8		4	10	3	8	1	7
Vindictive	74	1758	176	13	3	17	8	14	3	18	3		4	5	4	0	1	6
FOURTH RATES.																		
Elephant	58	1617	162	12	6	17	8	15	0	18	1		5	2	3	1	1	9
Leander	60	1572	157	9	6	13	3	12	4	16	4	Built of fir.	3	9	4	0	1	3
Liffey	50	1260	175	9	6	12	6	12	3	15	6		3	0	3	3	1	0

TABLE, *showing the Difference by the Stern of the Draught of Water, &c.—(continued.)*

SHIPS' NAMES.	Number of Guns.	Tonnage.	Quantity of Ballast.	Light Draught of Water. Forward.		Light Draught of Water. Aft.		Draught of water with ballast stowed, and lower masts and bowsprit stepped. Forward.		Draught of water with ballast stowed, and lower masts and bowsprit stepped. Aft.		REMARKS.	Difference by the stern of the light draught of water.		Difference by the stern of the draught of water with ballast stowed, and lower masts & bowsprit stepped.		Proposed difference by the stern when fully equipped for sea.	
			Tons.	Ft.	In.	Ft.	In.	Ft.	In.	Ft.	In.		Ft.	In.	Ft.	In.	Ft.	In.
FIFTH RATES.																		
Belvidera	42	946	94	10	9	14	10	12	5	15	10		4	1	3	5	1	4
Blonde	46	1103	110	10	6	13	9	11	11	14	8		3	3	2	9	1	1
Dartmouth	42	952	120	10	8	13	11	12	7	15	7		3	3	3	0	1	1
Lacedemonian	46	1073	90	10	5	14	9	11	10	15	10		4	4	4	0	1	6
Laurel	46	1088	108	10	7	14	5	12	6	15	8		3	10	3	2	1	3
Maidstone	42	947	194	10	9	15	0	12	6	16	6		4	3	4	0	1	5
Nymphe	46	1087	108	10	5	14	4	12	3	15	3		3	11	3	0	1	3
Pallas	42	951	95	10	8	14	5	12	7	15	7		3	9	3	0	1	3
Spartan	46	1084	108	10	4	15	0	12	8	16	0		4	8	3	4	1	6
Tiber	46	1215	130	8	8	13	1	10	6	14	6		4	5	4	0	1	6
Undaunted	46	1085	120	10	6	14	6	12	7	15	11		4	0	3	4	1	4
SIXTH RATES.																		
Athol	28	503	100	8	8	11	3	10	5	13	6	Built of fir.	2	7	3	1	0	10
Mersey	26	451	90	9	0	11	10	10	3	13	4		2	10	3	1	0	11
North Star	28	501	50	9	9	11	8	10	8	12	10		1	11	2	2	0	8
Ranger	28	502	80	9	6	12	0	10	6	13	9		2	6	3	3	0	10
Samarang	28	500	50	10	2	12	4	10	5	13	5	Built of teak.	2	2	3	0	0	9
Towy	26	448	65	7	7	12	5	9	11	13	5		4	10	3	6	1	7
Tyne	28	598	70	10	11	13	3	12	0	14	9		2	4	2	9	0	9
Volage	28	516	83	9	9	12	2	10	8	13	11		2	5	3	3	0	10

TABLE, *showing the Difference by the Stern of the Draught of Water, &c.—(continued.)*

SHIPS' NAMES.	Number of Guns.	Tonnage.	Quantity of Ballast.	Light Draught of Water.		Draught of water with ballast stowed, and lower masts and bowsprit stepped.		REMARKS.	Difference by the stern of the light draught of water	Difference by the stern of the draught of water with ballast stowed, and lower masts & bowsprit stepped.	Proposed difference by the stern when fully equipped for sea.
				Foward.	Aft.	Forward.	Aft.				
CORVETTES & SHIP SLOOPS.			Tons.	Ft. In	Ft. In.	Ft. In.	Ft. In.		Ft. In.		Ft. In.
Champion	18	456	53	10 8	10 10	9 11	13 3		0 2	3 4	0 0
Esk	20	458	61	8 6	9 8	9 11	11 11		1 2	2 0	0 5
Espiegle	18	386	54	6 3	11 6	8 2	13 5		5 3	5 3	3 2
Martin	18	400	47	9 6	11 3	10 0	12 6		1 9	2 6	0 7
Rose	18	398	40	8 8	10 11	9 5	12 6		2 3	3 1	0 9
Sparrowhawk	18	385	40	5 9	10 11	8 6	13 2	Unmasted.	5 2	4 8	3 1
Wasp	18	387	40	6 9	11 1	8 3	12 9		4 4	4 6	2 7
Wolf	18	454	53	10 9	10 10	9 11	13 3		0 1	3 4	0 0
BRIGS.											
Harrier	18	386	37	7 6	11 6	7 3	13 0		4 0	5 9	2 5
Rifleman	18	387	37	6 8	11 2	7 7	13 0	Bowsprit on deck.	4 6	5 5	2 9
Pelican	18	385	37	6 6	11 1	7 7	12 9		4 7	5 2	2 9
Manly	gun br.	180	25	6 8	8 10	8 0	10 3		2 2	2 3	0 8
Clinker	gun br.	183	24	7 3	8 9	7 6	10 6		1 6	3 0	0 6
Ferret	10	237	23	7 7	9 2	8 0	11 2		1 7	3 2	0 6
Icarus	10	234	32	7 0	9 3	7 11	11 6	Unmasted.	2 3	3 7	0 9

ART. XXXIV.—*Proposed Alteration in the Method of Fitting the False Keels of Ships.* By Mr. CHARLES WILCOX, of his Majesty's Dock-yard at Portsmouth.

IN consequence of the labour and expense attending the present methods of fitting the false keels, and from their not being so readily carried away when the ship strikes the ground as might be frequently desirable, it has been thought by the writer of this article that some alteration might be advantageously effected in this part of the fitting of a ship.

As the intention in fitting false keels to ships, independent of enabling them to hold a better wind, is merely as a protection to the main keel, and that they may be beaten off in the event of the ship's striking the ground, in order to free her from the obstacle without more serious damage, the writer thinks that in the usual manner of fitting the pieces of false keel, they are unnecessarily long; and that instead of their being from twenty to thirty feet in length, short pieces would be much less expensive, would answer every purpose above mentioned equally well, and would indeed be more readily carried away on coming in contact with any-thing which might otherwise tend to compromise the safety of the ship.

Besides which, the means of repairing such damage after ships are in dock would be greatly facilitated. Many instances have come before the writer's notice when ships have been taken into dock to be examined after they have been aground, or have struck on a rock, in which the blow has been found to have been near the middle of a long piece, which, in some instances, has been broken away, leaving two ragged ends still attached to the keel. Other cases have occurred where one end has been protruding very considerably beyond the side of the main keel, and sometimes the whole piece has been out of place from one end to the other, yet not carried away according to the intention of its being fitted, which shows clearly the propriety of some alteration, that ships may, under such circumstances, be more readily disengaged from what they may run on.

It is therefore recommended, that the pieces of false keel should be each about eight feet long, butting square against

each other, with a tie bolt driven through the ends to prevent their being split.

The fastening to the main keel, to be according to the present mode. In disposing the pieces care should be taken to place one of the pieces of false keel directly over every scarph of the main keel, and the space between these pieces should be then filled in with pieces as near the length of eight feet as the distance between the pieces covering the scarphs of the main keel will admit. When there are two false keels, as is often the case, the buts of the piece composing the lower one should be placed in the middle of the pieces above, thereby giving scarph to each other alternately. The blocks in the dock on which the ship rests are about four feet asunder; consequently, in order to shift a piece of false keel thirty feet long, it would be necessary for the ship to be shored and suspended throughout that space, so as to take out six or seven blocks to clear it. And should there be two false keels, double the number of shores would be required, as fourteen or fifteen blocks must then be removed to take down the two lower pieces, which the upper piece is connected with, for the purpose of clearing it.

Again, when it is found necessary to suspend a ship for caulking the garboard seam, and the scarphs of the main keel, the short pieces and copper sheathing on the under side of the main keel, covering the scarphs, would only require to be taken down for that purpose; if there were only one false keel, seldom more than one block under the scarphs need be removed; if two false keels, seldom more than two blocks; which will admit of the two lower and one upper piece being taken down. This mode of fitting would supersede the necessity of suspending a part of the ship in shores, when one piece of false keel only is required to be shifted, and would, in the opinion of the writer, be found beneficial were it generally adopted.

With false keels fitted on this plan, if the ship were to run on a shoal, or rock, a very trifling lateral resistance produced by veering or otherwise, it must be very evident, would carry the false keel away, and the ship would most probably be freed from her danger.

ART. XXXV.—*An Improvement on the Sextant.* By Lieut.-Colonel BAINBRIGGE, A. Q. M. G.

CONSIDERING that the common pocket sextant was capable of improvement, the writer had an instrument made for the purposes of military surveying, on a similar plan to the one here described; and having found that considerable advantages are to be derived from this method of construction, he now offers it to the public with such further improvements as his experience has suggested.

The invention of Hadley's quadrant originated with the celebrated Dr. Hooke, was completed by Sir Isaac Newton, and first published by Mr. Hadley;[1] its shape is an octant, or the eighth part of a circle, and it is generally called an octant by foreigners.

The quadrant was afterwards enlarged to a sextant, so as to increase the angle to 120 degrees, it being found that the best mode of ascertaining the longitude was by measuring angles between the sun and moon and stars, which required an instrument of a more extensive range than the quadrant.

The shape of this improved instrument is a quadrant, or the quarter of a circle; but from its being more immediately an improvement upon the sextant, I have, in this description of it, called it a Sextant.

The following are the chief advantages it possesses over that instrument, as at present constructed.

First. The parallax is avoided, by which all the angles are brought nearer the truth. This is effected by causing the line of sight to pass through the centre of motion of the index glass. "To get the angle truly exact, the objects should be viewed from the centre of the index glass, and not from where the sight vane is placed."[2]

Second. One adjustment answers for all distances whatever: whether between objects on the earth, or between the heavenly bodies at infinite distances.

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[1] Encyclopædia Perthensis, vol. 18, p. 523.

[2] Geometrical and Graphical Essays, by George Adams. Corrected and enlarged by William Jones. Fourth edition; 1813. Pp. 266.

Third. There is no refraction from the glasses at adjustment, and there is less refraction throughout all the angles than there is with the common sextant; consequently there is less liability to error.

Fourth. The range is increased, so that an angle of 163 degrees may be taken at one observation.

Fifth. Angles between objects on hills and in vallies, are rendered *horizontal angles* with greater ease at the time of taking them.

Description and Use.

Fig. 108 represents the instrument in perspective. In the instrument intended to be here represented, the radius is only two inches and three quarters in length; it may, however, be made to any size.

A represents the index glass, having an oblong opening cut in the middle, to admit the line of sight. Fig. 111 shows the front of this glass, and fig. 113 the horizontal section through the centre; B, B, are the parts ground away in an inclined plane, in order that the sight may not be impeded in the extreme large angles.[1]

The line A C fig. 111 shows the centre of motion, which it must be observed is not in the centre of the glass, this is in order that there may be equal strength left on the sides at B, B.

Fig. 112 represents the back part, showing the dip and back plate.

C, in fig. 108, is the horizon glass, having a part in the middle left un-silvered and transparent for the line of sight to pass through. This transparent opening is shown at D, D figs. 114 and 115, which represent the front and back of this glass. F L G fig. 114 shows the silvered part.

The transparent part D corresponds in height (from the plane of the instrument H I, figs. 114 and 111) to the opening in the index glass, shown by the dotted lines connecting figures 114 with 111, and 115 with 112.

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[1] If it should be found that the parts B, B are too slight, and there is danger of the glass breaking, the glass may be larger, extending further to the right and left.

There is a small pin I at the bottom of the horizon glass, fig. 114, to go into a small hole in the base in the instrument, fig. 110, in order that the vertical line E O may never be thrown out of the vertical plane of the line of sight, in turning the screws at adjustment. The point I will then be a pivot on which the horizon glass will move at adjustment; and it will be exactly in the line E O, as shown at I, fig. 110, V, V, being the screw-holes.

E O, fig. 108, is the line of sight, passing directly through the centre of motion of the index glass A C, figs. 111 and 113. This line is perpendicular to the index glass when the index stands at O, and also perpendicular to the centre part D of the transparent space of the horizon glass. The vertical line E O, figs. 114 and 115, shows the vertical plane of the line of sight.

In taking an angle, the reflected object will be either at F or at G, fig. 114, either above or below the object seen at D, through the transparent part of the horizon glass. But if the reflected object is on ground *above* where the observer is standing, it will be reflected at F; and if on ground *below* him, it will be seen at G. Should the other object be situated on ground *above* where the observer is standing, whilst the reflected object is on ground *below* him, then that other object which he looks at direct, will be seen above the horizon glass at H, and vice versa, through the opening at K below; observing always that the instrument must be held horizontally, and that the objects on the vertical line E O are perpendicular to the horizon.

The sight vane is made very large, projecting on each side so as to shut out the rays of light from the eye; thus increasing the power of vision, and rendering a telescope the less necessary.

An inverted telescope is applicable to the instrument, and may be affixed with ease.

In figs. 108 and 109, I is the sight hole—an oblong opening, corresponding in height to the opening in the index glass.

J, in fig. 108, is a green shade glass, to cover the sight hole at pleasure; this shade will be sufficient for the ordinary purposes of surveying, or it might be omitted altogether; but for solar observations this must be a dark shade.

K (fig. 109) is a frame to carry two shade glasses, one dark, the other green: these, with the glass J, will be used when taking the sun's altitude with the artificial horizon, where the rays reflected from that surface will be about equal to the rays reflected from the glasses, and will require equal shade.

These three glasses will also be required for all celestial purposes.

L, in fig. 108, are three other shade glasses, two dark and one green, fixed to the base of the instrument, to move up and down and cover the back of the horizon glass. By the aid of these glasses one may look directly at the sun. For expeditious surveying it will be sufficient if the arc is graduated to single degrees (the radius being not less than $2\frac{3}{4}$ inches), as it will prevent the necessity and incumbrance of a magnifying glass. In this case the vernier is made to read off to the $\frac{1}{6}$ part of a degree, which is effected by taking 5 divisions on the arc A B, fig. 116, and dividing it into 6 parts, C D, on the vernier (of course six lines only will be cut: the seventh line coming where the letter D is placed, will not be cut). The alternate divisions which mark 20 and 40 minutes should be longer lines than the others, having a small 2 and a 4, as in fig. 116. The divisions on the arc, as well as those on the vernier, should be very short, deeply cut, and very distinct to the naked eye; there should be no parallel lines, as they only confuse the sight. By attending to these particulars the magnifying glass is saved, and time is gained in the reading off of the angles. The plane surface of the vernier should be in the same line, or flush, with the arc, as shown in the section, fig. 117, A being the vernier, and B the arc; by which the same shade of light falls on both arc and vernier, and the eye will more readily distinguish the coincidence of the divisions. The part of the index which presses on the arc should be the under part C, in order that the part where the degrees are marked should not be worn bright, and thus dazzle the sight.

N, in fig. 108, is a ledge on the outside of the graduated part of the arc, on which the vernier P runs; by which the vernier is flush with the upper surface of the arc, as shown in the section, fig. 117.

The handle H (fig. 108) is made to turn on a hinge, con-

trived to go always stiff, for the convenience of holding the instrument in any position. The holes give firmness in holding it, and render it lighter. When put into the case the handle is turned up, and, by pressing against the case, prevents all jolting, and keeps the glass free from the danger of derangement.

Adjusting screws may be fixed, as with all other instruments of this kind; but none are put to this instrument, for when once firmly adjusted by the maker it will not easily get out of adjustment. Adjusting screws, however, are necessary to an instrument made on this plan for solar observation, where great accuracy is required.

The back observation is applicable in the following manner: —Let A, A, fig. 110, be a frame of brass made to carry the back horizon glass B, the back sight vane C, and the glasses D. The shade glasses would be removed from G to D for the occasion. This frame would be fixed with three screws E, E, F, whenever this observation might be wanted. The arc at F of course would be made so as to receive the screw-hole. H is the index glass, the index standing at Q at adjustment, when the horizon in the direction H K would be received into the index glass, and reflected back upon the horizon glass B.

The plane of the horizon glass B L being perpendicular to H Q, the plane of the index glass, the eye at C sees the reflected horizon at B, and also the unreflected horizon in the direction M, through the transparent part of the horizon glass. The index would move from Q to P, 95 or 100 degrees, which would be sufficient.

The inconveniences and inaccuracies attending the adjustment for the back observation render it an observation very seldom had recourse to.

Fig. 118 shows the plan of construction of Hadley's quadrant and sextant, and fig. 119 the construction of the improved sextant.

A B, (in both figures) the index glass, the index at O.

C D, the horizon glass.

O G, the line in which the reflected object is received into the index glass.

G F, the line in which that object is reflected back upon the horizon glass.

F E, the line in which the same object is reflected to the eye at E.

E F O, the line in which the eye looks through the transparent part of the horizon glass at the object O.

In figure 118 the angles O G A, F G B, G F D, and E F C, being all oblique, and the line E O passing obliquely through the glass C D, there are no less than five points of error upon the principle of construction; these errors may be all very trifling in small angles where the obliquity is not very great, and the intelligent workman allows for them; still they are errors, and they arise from the circumstance of the points E G F O not being in one right line, and from the circumstance of the impossibility of placing the eye at the centre of motion of the index glass.

The construction of the improved sextant rectifies these errors as much as possible.

The lines O G and EO, fig. 118, not coinciding, the space between them is called the parallax, and it is owing to this that a fresh adjustment is required at different distances.

Now in the principle of construction of the improved sextant, fig. 119, the index glass A B and the horizon glass C D are both perpendicular to the lines O G, G F, FE, and E F O; and as these lines are all in the same vertical plane, they may be said to coincide (taking a vertical view of them), and thus the parallax is avoided.

In like manner the glasses may be said to be perpendicular to these lines, and consequently there is no refraction which produces error, for the very small obliquity with which these lines strike the glasses acts vertically to the plane of the instrument, consequently the very small degree of refraction is produced vertically, and no error is the consequence.

The horizon glass, fig. 118, being required to be placed a considerable space from the line O G, the angle O G F is lost to the instrument; and as the objects within this space would have the last refraction from the index glass, they would be the most correct angles that could be taken. Now if this space be laid off in fig. 119; that is, the angle S G O made equal to the angle O G F, it will appear that the same refraction is produced from the index glass in fig. 118, when it stands at

O, as is produced in fig. 119, when it measures the angle S G O.

In like manner let the index glass in each figure be turned to L M, to take the greatest possible angle O G K, the angles of incidence K G L and of reflection F G M being all equal in both figures, there will be the same refraction produced in one index glass as in the other; yet in fig. 119 the angle measured will be the angle O G K, which is equal to the angle F G K in fig. 118. But as the angle F G K is composed of the angles O G F and O G K, and as the angle O G F is equal to the angle S G O in fig. 119; it follows that the angle measured in fig. 119 is greater than the angle measured in fig. 118, by all the angle O G F.

Consequently the further the horizon glass is placed from the line O G, the greater will be the advantage gained by the improved instrument. The common sextants therefore, where the reflected object is thrown out of the glass at 120 degrees, have the same error from refraction at that angle as the improved sextant has at 163 degrees. And in addition they have the refraction from the index glass, which is saved in the improved sextant.

The instrument will be found well adapted for all sorts of surveying, particularly for military and naval purposes on service, where great expedition is required, the increased range of angle giving it a decided superiority over the pocket sextant. In surveying with the latter instrument it not unfrequently happens, that on turning the index to measure a large angle the reflected object passes out of the glass; it is then found that the angle was too large for the instrument, and the observer is obliged to seek for another point from which to take the required angle. Time is thus lost—this is an inconvenience which cannot well happen with an instrument commanding an angle of 163 degrees.

Again, time is saved, and there is less liability to error, both in taking the angles in the field and afterwards in protracting them and making the calculations; by being enabled to take a greater number of angles from any one given point as a basis, than if obliged to make use of several different points; an advantage which this instrument possesses.

Where one cannot always choose one's station, large angles of between 140 and 160 degrees are occasionally wanted; in these cases the sextant is of no use, and the compass is tedious and uncertain. In taking soundings in a boat where the compass cannot be conveniently used, the large angles will be found of the greatest use. The bearings of ships and capes at sea are readily ascertained, the bearing of any one point by compass being once known.

In taking the sun's altitude on land, where the artificial horizon is required, the superiority of the instrument will be evident: for the observed angle being *double* the angle of the sun's elevation, a common sextant, which only takes an angle of 125 degrees, can only measure the altitude as high up as $62\frac{1}{2}$ degrees, whilst with the improved sextant the measurement may be carried on to $81\frac{1}{2}$ degrees. This difference of 19 degrees taken on each side of where the sun is vertical, makes a total space of 38 degrees, in which, with the common sextant, one must have recourse to double altitudes in the fore and after-noon; whereas with the other, a simple meridian altitude may be taken at noon. This would be a great advantage in central Africa, where the natives are inquisitive and jealous of instrumental observation, but where they are generally asleep at mid-day; the traveller then is better enabled to make his observations and calculations at this time than at any other in the four-and-twenty hours; whilst in the morning and afternoon, when the double altitudes would require to be taken, he might be on his journey or otherwise prevented.

The altitude of the sun may be taken at sea by looking directly at the sun, and bringing his image to the point D in the horizon glass fig. 114. The index is then moved, so as to bring the horizon by reflexion to F G, on each side the sun. This mode of taking an altitude is the reverse of the ordinary mode with the quadrant, but the angle is the same. In practice it may be found to have some advantages, as the eye will catch the sun sooner, and the observation will be made quicker than where the sun is seen by reflexion. The instrument of course is reversed: the left hand holds it and the right hand guides the index.

The instrument which the inventor had made on this plan,

was used by him in the Peninsula, and in France, when on the staff of the army in those countries, between the years 1810 and 1814, and he made many extensive surveys with it, which were completed more expeditiously and more accurately than he could have done them with any other instrument. These plans are all in the Quarter-Master General's office, at the Horse Guards.

It may be worth while to observe, that for solar observation with all sextants and quadrants, the dark shade glasses may be dispensed with by covering the index and horizon glasses with a thin coating of body water-colour, white lead, or yellow ochre, laid on not too thick; this has the effect of throwing a veil, as it were, over the sun's rays, sufficiently so as to enable one to look at it through the single green glass at the sight hole, which will not be too dark to obscure the horizon. The transparent part of the horizon glass of course must not be covered with the colour. Thus the mass of glasses between the index and horizon glasses in quadrants, which are a source of error, might be avoided. In this way the back observation may be taken with the same ease as the fore, no fresh adjustment being required; the angle of elevation being simply the supplement to the angle of the fore observation, allowing, of course, for the dip.

Art. XXXVI.—*Remarks on Stowing the Ballast.* By Capt. Philip Brown, R. N.

Unless the ballast is placed to accord with the vessel's construction, as well as to the proper position of the masts, it becomes necessarily detrimental to her best qualities. It often happens that a vessel of war is brought to the draught of water at which the builder determines she will best answer, more by her top-weight than by that of her stowage in the hold; and very seldom is much regard paid to the lines of her construction, provided she arrives at her destined draught of water. This mode of trimming a vessel must be evidently mischievous, as well as unjust to the science of the builder, and it too often occurs that odium is cast upon his

skill, which truly ought to attach to the unskilful person into whose hands such a ship may unfortunately fall; in truth it is utterly impossible that any vessels whatever, more especially those constructed for the purposes of war or fast sailing, can ever be expected to produce their best qualities, unless their commanders are competent to comprehend the construction and principle upon which they are built; and more vessels in His Majesty's service have arrived at good sailing by mere chance than by the actual knowledge of their construction. It likewise often happens that the person who has commanded a French ship that has sailed well, on being appointed to an English one, will stow and arrange her in a precisely similar manner, although the principles of their construction be wholly different. It is therefore much to be lamented that officers in the navy, when they have the opportunity, neglect to acquire a description of knowledge of so much consequence to their best interest; for theoretical and practical knowledge is of the utmost value; and it is equally to be lamented that the surveyors of His Majesty's navy, who are its principal constructors, whenever an improved description of ship is built by them, should not have a voice in the appointing a competent officer to command her; for in all matters of experiment, neither the rank nor quality of the officer should become a consideration; it is the ship, and not the rank, that should be the first consideration; for if one does not answer, the other becomes useless.

As the stowage of the ballast must materially govern the ship in all her motions, when operated upon by the elements with which she will have to contend, it is of the utmost consequence that while it should on the one hand enable her to resist the violence and power of the wind, it should also enable her to yield easily to the pressure of the water, so as to permit her to pass smoothly through and over the waves, preserving her equilibrium as much as possible on all occasions, neither depressing the one extreme nor the other, nor forcing beneath the water that part of her hull always intended to be above it, as well as neither placing it too high nor too low, to occasion violent rolling or the want of stability to carry canvass—both extreme evils.

Having a perfect knowledge of the ship's construction, on reference to it, it will be seen where her greatest capacity lies; within which it is advisable to confine the ballast as much as possible; for the weight in the extreme of ships of war is so great, that unless this precaution is taken, the vessel will be liable to pitch and 'scend excessively, endangering the masts and retarding her sailing; and again, if it be placed too high or too low, she will roll heavily.

If the weights be extended towards the extremities, their effect must be to increase the inclination, and consequently accelerate the pitching; confining or centring the weights diminishes the effect, and the vessel becomes less disposed to swag upon her axis; and the ballast being confined to that part of the body of the vessel best able to sustain its weight, will also render her less liable to swag either on the sea or on taking the ground.

Art. XXXVII.—*On the Protection of Ships from Lightning.* By W. Snow Harris, Esq., F.R.S.

1. The annals of the British navy during the last half century present few cases of damage, from natural causes, more calamitous than those which have resulted from discharges of atmospheric electricity. The disastrous effects of lightning on ship-board, whether considered as endangering the lives of the seamen, or as involving the national interests, are most appalling; and it becomes a question of serious importance to a maritime power like Britain, how far her fleets can be effectually secured against the destructive operations of one of the most powerful agencies in nature.

2. It may be remarked in considering this question, that the damage thus sustained by ships usually so occurs, as to excite rather a particular than a general apprehension, hence the accumulated evil is not fully apparent; indeed, an impression, that the chances of danger at sea from lightning are comparatively few and inconsiderable, aided perhaps by the notion somewhat prevalent amongst sailors, that the common methods of defence are in themselves objectionable, has caused the most

effectual means of palliating the fury of strokes of lightning on ship-board to be altogether overlooked.

3. It will be my endeavour to show in the course of these observations, and that too by adhering carefully to the only certain means by which science is advanced—observation and experiment—(1st), That the necessity of guarding the navy of of England against explosions of natural electricity involves a question of vital importance to the nation. (2dly), That the notion so frequently entertained, that lightning-protectors on ship-board are objectionable, as being calculated to *invite* the destruction which they are intended to obviate, is unfounded in fact: (3dly), That the most effectual method of rendering ships safe in thunder-storms, is by perfecting the conducting power of the masts themselves as far as possible, uniting at the same time by good conducting communications all the detached masses of metal, wherever it can be effected, and finally by completing the metallic connexions through the ship to the sea, or to the copper expanded on the bottom. (4thly), I shall endeavour to point out an efficient method of carrying these last suggestions into practice, and that in a way beneficial to the masts themselves, so that under all the varying circumstances and conditions of the ship, as complete a protection from the effects of lightning may be obtained as can reasonably be expected from the advances yet made in natural knowledge.

4. And first with regard to the importance of the question as affecting the interests of the nation. To render this apparent, little else will be required than a plain statement of the following instances of damage by lightning on ship-board.

(a) His Majesty's ship Russel, on the 5th of October 1795, was struck by lightning about three leagues from Belleisle, the explosion fell on the main and mizen masts throughout, and disabled the masts so much that no sail could be carried on them when it blew fresh. If the squall had lasted a few hours longer, the ship must have inevitably been lost on the French coast, as the wind blew right on.[1]

(b) In the year 1793 H. M. ship Duke, of 90 guns, com-

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[1] Naval Chronicle.

manded by Sir Charles Penrose, was struck by lightning off the Island of Martinique, *whilst in action under a battery, which shivered her main-topmast*, and did *other damage to the vessel.*[1]

(c) On the 23rd of February, 1779, H. M. ship Terrible was assailed by a stroke of lightning; the fore-top-mast and fore-mast were destroyed. The explosion made its way into a store-room directly over the fore magazine, and shivered two carlings in pieces. The officer on watch said the lightning ran in a circular stream down the foremast.[2]

(d) In the autumn of 1813 part of the Mediterranean fleet, under the command of Lord Exmouth, was struck by lightning off the mouth of the Rhone, so that out of 13 sail of the line *about one half were damaged*, at least 5 ships were obliged to shift their top-masts. The fleet was at this time employed in blockading Toulon.[3]

(e) H. M. ship Glory was struck by lightning off Cape Finisterre, in the fleet commanded by Sir Robert Calder, only a few days previously to meeting the combined fleets of the enemy. She was quite disabled in her main-mast, the top-gallant-mast and top-mast being rent from the head to the heel.[4]

(f) In the summer of 1830, H. M. ships Gloucester and Melville were both disabled by lightning, at Malta, whilst going out of port to join the Admiral, so that they were obliged to return and refit.

(g) In the year 1748, the ship Dover was struck by lighting, in lat. 47° 30′ north, long. 22° 15′ west, it disabled the main-mast, stove the upper deck, drove down all the cabins on one side of the steerage, stove the lower deck, went through the starboard side, and started off from the timbers four outside planks, one of which planks, being the second from the wale, was broke quite asunder, *and let in, in about ten or fifteen minutes' time, nine feet of water in the ship.*[5]

(h) H. M. ship Cambrian was struck by lightning off Plymouth, on the 22nd of February 1799, which fell on the fore-mast, killed two men at the bitts, and wounded several

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[1] Naval Chronicle. [2] Admiral Bedford, R. N. [3] Capt. Barnard, R. N.
[4] Lieut. Boucher, R. N. [5] Philosophical Transactions.

others, the lightning passed into the waist and struck down almost every one on that side of the deck—the number of wounded men taken below, many of whom were insensible and apparently dead, was about twenty—the appearance of the ship was distressing in the extreme, nor could the men, for months after, get rid of the impression produced on them, whenever the elements were surcharged with the electric fluid.[1]

(i) H. M. ship Windsor Castle was struck by lightning in Leghorn Roads, in September 1794; the parrel between the mast and yard was set on fire; and it burned so furiously, that had not very heavy rain come on, there is little doubt but that the ship would have been destroyed.[2]

5. These few instances of damage by lightning at sea, are alone calculated to excite reflections of the greatest national importance.

The first (a) is a powerful illustration of the hazardous situation in which a ship of the line was placed from the above cause, when on an enemy's coast.

The second (b) is an instance of a ship being to a great extent disabled by lightning whilst in action.

The third (c) shows the liability of a stroke of lightning to explode in the vicinity of the powder magaz nes.

The fourth (d) is an instance in which one half of a fleet employed in blockading an enemy's port, were in some measure disabled from the same cause. The disadvantage to the country, had the ships been then called into action (a supposition by no means unwarranted), is almost incalculable.

The fifth (e) is of the same nature.

The sixth instance (f) is again similar, inasmuch as the absence or presence of two ships of the line may be sufficient to decide the result of a general action; now these ships were disabled when about to join a fleet; and we may suppose it to have been a case of emergency.

The seventh (g) proves, that a vessel may be nearly torn in pieces by the violence of a stroke of lightning.

The eighth (h), beside the loss of life, is an illustration of the

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[1] Capt. Haydyn, R. N.   [2] Capt. Bevins, R. N.

unpleasant effect produced on the minds of the ship's company, tending to paralyze their necessary exertions in times of difficulty.

The last instance (i) shows, that a discharge of atmospheric electricity may be the cause of a ship's being destroyed by fire.

6. It is not therefore unreasonable to infer, from an attentive consideration of these and similar instances, that many ships, whose loss, from the length of time they have been missing, amounts to a certainty, have been, directly or indirectly, destroyed by lightning; for whilst ships remain undefended from this source of danger, there is no fatal consequence incident to their situation by which they may not be suddenly assailed: the impolicy of allowing a country like Britain, whose naval pre-eminence is so intimately connected with its national greatness, to remain exposed to these fearful contingencies, when in all reasonable probability such may be avoided, cannot, for an instant, be questioned.

7. Having thus set forth the national importance of this question, we now proceed to consider the method of defence by lightning-protectors, first suggested by the celebrated philosopher Dr. Franklin, and during a long period employed in defending powder magazines and other buildings of consequence on shore with considerable success; and also to show, that the objections which are advanced to the use of such protectors when efficiently applied to ships, are inconsistent with the known laws of electrical actions, and unfounded in fact.

8. Although the meteorological phenomena occasioning damage to ships are in some instances of an anomalous character, and have been classed under the general denomination of fire balls, yet such damage is for the most part observed to happen during that peculiar state of atmospheric excitation constituting a thunder-storm, the more immediate subject of our present consideration.

9. The active principle of a thunder-storm may be considered as an extremely subtle species of matter, every-where pervading nature, being distributed in bodies, in quantities proportionate to their capacities for it; the real essence, however, of this wonderful agency is as yet undiscovered: it has been occasionally termed, the matter of lightning, or more commonly

electricity, or the electric fluid, in consequence of its intimate identity with the cause of the phenomena observed on exposing vitreous and resinous substances to a sort of excitation by friction.

The quiescent state of this very subtle principle seems to consist in the proportionate distribution above-mentioned; whenever therefore from any cause it becomes disproportionately distributed, that is to say, whenever it is accumulated in or about certain bodies, and abstracted at the same time from other bodies, there ensues a tendency more or less powerful, according to the extent of the disturbance, to regain the previously-existing state: in this way a sort of concentrated action is at length set up between the overcharged and undercharged bodies, which frequently ends in a terrific explosion, and the electric matter assuming a highly-condensed form in the act of rushing from the one to the other, exerts upon such substances as lie in its course an irresistibly expansive effect, accompanied with a rapid evolution of light and heat; so that such substances are not only rent asunder, but are frequently inflamed, fused, or ignited.[1]

10. In the progress of electrical inquiries it has been found, that some substances oppose but comparatively little resistance to the passage of the electric principle, whilst on the contrary others seem to arrest its course altogether; hence electricians have been led to consider bodies in relation to their resisting power: substances which oppose but comparatively little resistance to the passage of the electric matter having been termed *conductors* of electricity, whilst those which oppose its passage altogether have been termed *non-conductors* of electricity, or occasionally, from the same cause, *insulators*.

11. The conducting class comprises, all the metals, concentrated acids, well-burned charcoal, wood in its ordinary state, dilute acids, and saline fluids, most earths and stones, flame,

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[1] This easy and elementary view of electrical action may not be altogether out of place, for although it must be admitted that a theory is merely a way of picturing to ourselves the course of nature, yet it is always sufficient and admissible so long as it is consistent with observed phenomena and not contradicted by any known fact.

smoke, steam, and a highly-exhausted medium. If any of these substances while resting on the ground be put into contact with the conductor of an electrical machine, whilst a current of sparks is passing from it, the sparks will immediately cease, in consequence of the electric matter being rapidly transmitted by them to the earth—an easy and striking experiment.

12. In the *non-conducting* or *insulating class* are found, all vitreous and resinous substances—dry, permanently-elastic fluids such as air: silk, oils, wool, hair, feathers, baked wood, and very dry vegetable substances. If whilst a current of sparks is passing from the conductor of an electrical machine any of these bodies be put in contact with it, resting as in the former case on the earth, little or no difference will be perceived; the sparks will continue.

13. Although for general purposes the various bodies in nature may be considered as belonging to one or the other of these classes, yet such a gradation of effect is observable that the conducting or insulating power of some substances, as compared with that of others, may be considered imperfect: hence has arisen a third class, which may be referred to either. Thus, wood, hemp, stone, and the like, may become insulators to a state of low electrical action, and conductors to an intense one.

14. The manner in which accumulations of atmospheric electricity proceed, are referable to the following principle: When two substances of the conducting class are directly opposed to each other, and are separated by a substance of the non-conducting or *insulating* class, one of the conducting substances being in a free state, whilst the other is insulated; the state of proportionate distribution (9) may then become deranged to the greatest possible extent, causing an intense electrical action.

These conditions are found in nature, in the relative situations of the sea and clouds, and intervening air; so that when from any cause an evolution of natural electricity takes place, and heavy masses of vapour are present, we have immediately an insulated conductor (a cloud) opposed to a conductor in a free state (the sea or land), and an intervening insulating medium (the air); hence results a charged battery of enormous power:

and the attractive force of the opposite electrical states becomes at length so powerful that the electric matter breaks down the intervening resisting air with a terrific and dense explosion, falling either upon the surface of the sea or land, or otherwise upon such elevated bodies as happen to lie in the vicinity of the point in which the intervening air gives way. This peculiar effect is perfectly analogous to the spontaneous explosion which frequently occurs at the time of conveying a high charge to an electrical jar, and which is attended by a peculiar fracture of the glass.[1]

15. The year 1752, which marks an important era in electrical science, from the celebrated discovery of the principle above-mentioned, under the form of the Leyden jar, gave to the natural philosopher an easy method of concentrating large quantities of electricity produced by artificial means, so as to discharge it upon or through bodies with an instantaneous and violent explosion. From the time therefore that the cause of lightning became *identified* with that of ordinary electricity, and the gigantic attempt of Dr. Franklin and other philosophers, of actually drawing down the matter of lightning from the clouds, was fully accomplished, the effects produced on bodies by minor electrical discharges, with their mode of action, acquired a new interest; and many important experimental

[1] When sensible and heavy masses of vapour are *not present* so as to form an upper and insulated conductor, the arrangement may then be considered to be simply that of a single conductor in a free state, and a contiguous insulating medium, the latter being either in an overcharged or undercharged state, as exemplified mechanically in placing a square of glass, previously electrified either positively or negatively, upon an extended surface of tinfoil; under these circumstances a large quantity of the accumulated electricity may rush through some weak portion of the insulating air, producing that species of meteor termed more especially a fire-ball, and which is observed to occur even in serene weather. In a similar way the luminous appearances observed occasionally on the pointed extremities of a ship's masts and yards are referable to the more gradual passing of the electric matter existing in the atmosphere in a free state, and which frequently occurs in very fine weather without the presence of clouds: but whatever form these explosions assume, they may be all considered as originating in the same cause; the tendency of the electric matter to a state of proportionate distribution. An explanation of the phenomena of thunder-storms on this principle will be found in my printed letter to Sir T. B. Martin, G. C. B., Comptroller of his Majesty's Navy, &c.

researches into the laws and operation of the great natural action were successfully carried on by means of the ordinary artificial one.

16. Amongst the many important results arrived at by such inquiries are the following:—

First—In every case of electrical explosion, there are universally two points of action, one *from* which the electric matter may be supposed to proceed, and another *towards* which it may be considered as determined.

Secondly—At the instant before which an explosion takes place, the stream of electricity moving to restore the equilibrium of natural distribution, seems, by a wonderful influence, to feel its way, and mark out as it were in advance the course it is about to follow; which course is *invariably determined through the line or lines of least resistance* between the points of action.

A few illustrations from experience of damage by lightning, in addition to those before-mentioned, may serve to render these facts evident.

(k) The brig Belleisle of Liverpool, in November 1811, was lying afloat, abreast of Mr. Evans's yard, at Bideford, when a vivid flash of lightning shivered her fore-top-mast and fore-mast, tore up the forecastle deck, and struck a hole through her starboard-side, starting several butts in the bends, whence it passed into the sea.

(l) The United States ship Amphion, Blone master, of, and thirteen days from New York, bound to Rio, was struck by lightning on the 21st of September 1822, the lightning descended by her mizen-mast, destroyed the compasses and cabin furniture, splintered and tore to pieces the ceiling, bulk heads, and rudder trunks, shivered two hold beams, and passed out *through the quarter into the sea*, tearing off part of the sheathing in its course.[1]

(m) His Majesty's frigate Palma, commanded by Captain Worth, was struck by lightning in 1814, in the harbour of Carthagena, Spanish America; the fore-top-mast was knocked

[1] Extracted from the Log of the brig Mirabiles, and given to Mr. Lockyer, Comptroller of the Customs at Plymouth.

over the side, the lightning guttered or scooped its way, two inches deep and one inch and a half wide, under the hoops of the mast, without injuring them, as far as the main deck; here it fell upon the wet cable which had been just shortened in, and was lying against the after beam; it knocked out a piece of the beam, and passed by the wet cable out of the hawse-hole, the lead of which bore evident marks of the explosion. It was perfectly calm at the time, and the lightning, besides striking the ship, *struck also down upon the sea* several times, and within a short distance of the ship.

(n) The packet ship New York, in her passage from New York to Liverpool, was struck by lightning twice in the same day, April 19th 1827. The first explosion shattered the main-royal-mast and mast-head, penetrated the deck, and demolished the bulk-heads and fittings in the store-rooms below,—then dividing, one part fell upon a lead tube, which it traversed as far as the side of the ship, and passed out into the sea, starting the ends of three four-inch planks; another portion passed into one of the cabins, and shivered to atoms the plate of a large mirror, without hurting the frame; after this, it fell upon a piano-forte, which it touched with no very delicate hand, and left it dismounted and out of tune; thence it passed through the whole length of the cabin floor, which was damp at the time, and out of the stern windows into the sea.

(o) The operation of the second explosion was very different from this;—it fell upon a spike at the mast-head, and thence passed down a small metallic chain, which it disjointed and partly fused, into the sea, without doing any damage to the vessel.[1]

(p) In January, 1830, H. M. ship Etna was struck by lightning, in the Corfu Channel in the Adriatic; in this instance three tremendous explosions came down a metallic chain attached to the main-mast, and passed into the sea, without damage to the vessel.

It may be observed by these few cases, first, that the points *to* and *from* which the electric matter eventually passes are out

[1] This conducting chain had been set up immediately after the first explosion happened.

of the ship; and according to what has been already stated (13) are in the sea and clouds, hence the ship is merely an intervening object: cases g, k, l, m, n, o, more particularly show this. Secondly, that the points through which the explosion is determined, are invariably in the line or lines of least resistance between the points of action, that is through the best conductors: cases m, n, o, more particularly illustrate this, and the same may be traced in all the others.[1]

17. We may further observe in these, as in every other case of damage on ship-board, that the greatest mischief occurs where good conductors cease, as if whilst occupying the conducting substances, the electric matter became diffused and in a low state of tension, and was again concentrated and brought into a state of great activity at the instant of leaving it; thereby producing all the disastrous consequences of an irresistibly expansive force. The damage therefore may be considered to happen not where the best conductors *are*, but where they *are not;* so that the mariner has to contend with a constantly-exploding principle, which continues its devastations in all those points where it ceases to be transmitted: thus determining for itself a passage between the points of action through such line or lines as may upon the whole oppose to it the least resistance.

18. These effects being constant, not only on ship-board but on shore, it became a grand question in science, how far it would be prudent to provide an efficient conducting line for the electric matter, between the points of action, so as to offer the least possible resistance to the progress of so powerful an agency, and thus transmit it as it were in a state of low tension to the sea; on the same principle that persons dreading an inundation would provide a channel for the water to flow through, with as much ease as possible, an idea, as is well known, first suggested by the celebrated Franklin, and since carried into practice with considerable success; the conduct-

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[1] The only action which can be conceived to belong exclusively to the ship is that depending on the opposite electrical state of the whole mass of the vessel, as being a point of the great surface opposed to the electrified clouds, and which is evidently of little consequence compared with the immense capacity of the surrounding sea.

ing line having received the name of *lightning-conductor*, or *lightning-rod.*

19. The objections made to fixing such lightning-conductors in ships, are such as have been urged against the principle generally, and are for the most part as follows:—It is said, that by providing ships with lightning-conductors we *invite* an electrical discharge from the atmosphere, and that by means of an attractive power, which it is assumed all metals possess, the explosion is drawn exclusively upon the vessel, when otherwise such would not occur; that inasmuch as we can never come to know the absolute quantity of electricity which may be discharged from a thunder-cloud, it is possible that the transmitting power of any conductor we can apply may be inadequate to the end in view, hence it is inferred that great damage may be the consequence. Such are the powerful objections to the principle, which it is hoped are fairly stated; they are highly deserving of serious consideration, and it will be my endeavour by a candid inquiry to give them all the attention they demand; keeping in remembrance at the same time the beautiful aphorism of Lord Bacon, "Man, who is the servant and interpreter of nature, can act and understand no further than he has, *either in operation or in contemplation, observed of the method and order of nature.*"

20. The notion that a lightning-rod is a positive evil, will be found to have arisen not out of any legitimate knowledge acquired by actual experience, but from assumptions or partial facts, such as that above-mentioned (16), namely, the passage of the matter of lightning through the line or lines of least resistance between the points of action: in consequence of which it is observed to fall on bodies the least calculated to oppose its progress, such as metallic vanes, vane spindles, iron bars, knives, and pointed metallic substances generally; all of which will be commonly found in the course of the explosion. It is indeed solely from this circumstance, that metals have been considered to attract lightning and draw it down upon substances in connexion with them.

21. It will be found, however, that the action of pointed metallic bodies is purely passive; that they only afford by the aptness of their parts an easy transmission to the electric mat-

ter, which is in fact already present, and is operating *on them* in common with other substances. So that they can no more be said to attract exclusively the matter of lightning, than a dyke can be said to attract the water which necessarily flows through it at the time of heavy rain; and as in the one case the water is drawn down by a force not peculiarly appertaining to the dyke, so in the other case the electric matter is determined to a given point, in a somewhat similar way, by a force not appertaining to the metal. Moreover, it may still further be reasoned by analogy, that as the quantity of water transmitted will depend on the capacity of the dyke, and the final protection it gives in conveying the fluid on the length to which it is continued; so, on the other hand, the protection afforded by a lightning-rod will also depend on *its* capacity, and the distance to which it runs. If in both cases the length be extended until the force in action be satisfied, the protection received will be as the capacity for transmitting the current: if both be perfect, the protection will be complete; if the dyke be not present, the water must be supposed to run loose and undirected; or if its continuity be frequently interrupted or narrowed to a small compass, the damage must then be supposed to happen in the intermediate spaces. Such is in fact the way in which all bodies of the conducting class already mentioned (11) operate in conveying electrical discharges: and it must never be forgotten as an important feature in this discussion, that whenever we erect an artificial elevation on the earth's surface in the ordinary way, we do in fact set up a conductor of electricity upon which the electricity of the atmosphere will fall, and no human power can prevent it. Hence if metallic bodies be present, those will be first assailed: if not, then the electric matter will fall on the bodies next in conducting power, and so on.

22. A curious illustration of this principle will be found in an extract from the memoirs of the Count de Forbin, which is given in the forty-eighth volume of the Philosophical Transactions. "In the night," says the author of these memoirs, "it became extremely dark, and it thundered and lightened dreadfully. As we were threatened with the ship being torn to pieces, I ordered the sails to be taken in; we saw upon dif-

ferent parts of the ship above thirty St. Helmo's fires, amongst the rest there was one upon the top of the vane of the main-mast, more than a foot and a half in height; I ordered one of the sailors to take it down. When this man was on the top he heard this fire; its noise resembled that of fired wet gunpowder. I ordered him to lower the vane and come down, but scarcely had he taken the vane from its place, *when the fire fixed itself upon the top of the main-mast*, from which it was impossible to remove it."

23. Since, then, the conducting power of bodies differs only in degree; and that the action by which they are assailed is the result of a great natural agent, quite independent of them, we may expect to find all bodies liable to be assailed by lightning, though the effects may be most apparent when the conducting power is imperfect. Thus we find cases on record, of ships struck by lightning, in which no metallic spindles were present, or other iron-work about the mast-head:[1] moreover, it is by no means an uncommon circumstance, to find trees and rocks rent asunder by lightning; and to hear of men and quadrupeds, even in a plain and open country, destroyed at the time of a thunder-storm, when the electric matter strikes the earth's surface.

24. *Experience* shows that lightning-rods have no such attractive power as that attributed to them; and that ships are equally open to atmospheric electricity, whether furnished with lightning-rods or not. In proof of this position, we shall cite the following cases:—

(q) His Majesty's ship Milford was struck by lightning, in Hamoaze, in January, 1814, and the temporary mast fixed in her, greatly damaged. This ship *had not* a lightning-conductor at the time; but there were many other ships *close by*, and a *powder magazine*, all armed with this means of defence, terminating in points; *but these were not assailed* by an explosion, so that no damage whatever occurred to them.

(r) His Majesty's ship Norge, at anchor in Port Royal harbour, Jamaica, June 1815, was severely damaged by light-

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[1] See Philosophical Transactions, vol. 49 and 69, damage done to the sheer-hulk at Plymouth, and on board the Atlas, East Indiaman.

ning, so that she was completely disabled in her masts and rigging. Several ships surrounded the Norge, but *none were* struck *except* a *merchant-ship, which, like the Norge, had not a lightning-conductor. All the other ships* had lightning-conductors up at the time. Amongst them was H. M. ship Warrior, of 74 guns; which ship was lying *close* to the Norge. The electric matter was observed, as appears by a very interesting account given by Admiral Rodd, "absolutely to stream down the conductor into the sea."

(s) To the instance already given of H. M. ship Etna, struck by lightning in the Corfu Channel, (p) may be added the circumstance of H. M. ships Madagascar and Mosquito being also near, and struck several times; the former having had her fore-mast and mizen-top-mast much damaged.

(t) The Heckingham poor-house, damaged by lightning, an account of which may be seen in the Transactions of the Royal Society, was struck at a point the *furthest* removed from the conductors with which that building was furnished.

(u) In the 14th volume of the Transactions of the Royal Society, there is a similar case of a long building, struck at one *end*, a conductor having been applied to the other; that is to say, the lightning *also* fell on a point the *furthest* removed from the conductor.

(v) The case of the New York packet-ship (n) (o), is also an instance of lightning having equally fallen on the ship, whether furnished with a lightning-conductor or not.

25. It may be further remarked, that lightning-rods have now been in use for upwards of eighty years, and applied to every magazine in Europe, without ill consequences, in virtue of any attracting power assumed to belong to them; and likewise to buildings and ships, in abundance: and from the whole course of experience, it will be found, that atmospheric discharges have almost invariably *occurred where lightning-rods have not been present;* that in the cases in which lightning-rods *have been present*, and *efficiently applied*, the damage has been avoided altogether.

26. Some further appeal to experience, from which we should never depart in inquiries of this kind, will illustrate very satisfactorily the operation of lightning-rods as a suc-

cessful means of defence in thunder-storms—the cases (n) (o), already alluded to, are striking illustrations: indeed, if a great natural experiment could have been instituted for the purpose of determining the utility of a lightning-rod, such should have been the conditions under which it should have been placed. In a memoir presented to the Royal Academy of Sciences at Paris, in the year 1790, by the celebrated French philosopher Le Roy, we find two French frigates successfully protected by lightning-conductors, which completely disarmed the fury of the vivid flashes that assailed them, and transmitted the electric matter securely to the sea. In Mr. Kinnersly's account of the stroke of lightning which assailed Mr. West's house in Philadelphia,[1] we find that the lightning-conductor effectually performed its office. Charles' church and steeple, at Plymouth, struck by lightning a few years since, were protected in a similar way; the electric matter passed down in a dense stream over the conductor into the ground, tearing up the ground in its course. It is worthy of remark, that, of six church towers in Devonshire, struck by lightning within a few years, the only one which escaped damage was the church at Plymouth, which last was also the *only* one defended by a lightning-conductor. The cases of the Warrior and Norge already mentioned, are also striking instances. In the fifty-second volume of the Transactions of the Royal Society, there is an instance mentioned of a ship, called the Generous Friends, twice preserved by a lightning-conductor. Captain Winn observed, that his chain-conductor was broken for a short distance above the ship's side, leaving an interval of about three-fourths of an inch; over this space the electric matter was observed to pass in the form of sparks, during two hours and a half, at the time of a thunder-storm.[2]

27. It is therefore by no means unreasonable to consider the conducting power of a lightning-rod, as arising not out of any attractive property inherent in it, but from an action purely passive; that is to say, the removal of resistance; indeed in the case of a vacuum, or rather a very finely-exhausted medium, which is found to answer the same purpose as a conducting body; since the electric discharge is freely transmitted through

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[1] Priestley's History of Electricity. [2] Trans. R. S.

it; we must necessarily admit the truth of the above principle; the conducting power here evinced must arise solely from the removal of a resisting medium; for what is equivalent, in a comparative point of view, to the absence of all substance, cannot be supposed to be endowed with any peculiar or positive quality. Now the circumstances attending the conducting power being precisely the same, whether we suppose the latter to be peculiar to a void, or to a positive substance; it is a legitimate deduction, and not contradicted by any known fact, that in either case the conducting power is dependent on the same cause; and is therefore a negative quality. In further confirmation of this notion, we find, that an artificial discharge will rather jump over an interval of air, than pervade a very extensive circuit of metallic wire; that is to say, when the resistance of the metal becomes *greater* than *that* offered by the interval of air, the electric matter will no longer pass in the best conductor, for it is no longer the *line* of least resistance.

28. With respect to the actual quantity of electric matter which may possibly be discharged in a thunder-storm, and the effect likely to be produced on lightning rods; that must altogether be determined by experience. It is by no means contended, that lightning-conductors operate as a *charm* or *nostrum;* but that they are a useful means of defence against such cases of damage as come within the experience of mankind; not against convulsions of nature, when it would be of no great consequence whether we had lightning-rods or not. It is therefore against such cases of damage as may be reasonably expected to occur, that we purpose to employ lightning-rods. Now we have the experience of nearly a century to guide us in this; we do not find in any case of damage by lightning at sea, that a quantity of metal has been melted equal to that contained in a copper bolt of half an inch diameter and six inches long; or otherwise, an equivalent quantity of any other metal, more easily fused by electricity;[1] on the contrary, we

[1] It has been recorded, that the great conductors of St. Paul's church in London had marks of having been made red-hot by lightning; but it seems on consideration, that inasmuch as these conductors were not minutely examined previously to the lightning which is supposed to have fallen on them, we can never be certain that the marks were not there originally, and resulted from the forging of them: moreover, it is difficult to imagine that a stroke of lightning

find that very heavy electrical discharges have been transmitted without fusion, by small masses of metal—amongst many instances, may be mentioned the following:—In the explosion which struck Mr. West's house,[1] the lightning fell upon a spike, ten inches long and a quarter of an inch in diameter—only *three inches* of the fine point were fused.—The spike of the conductor on the packet-ship, New York, and on which a tremendous explosion fell, consisted of an iron rod, four feet long and half an inch in diameter; it was only melted near its extremity, for a *few inches;* the chain-conductor consisted of iron wire, of one quarter of an inch in diameter, yet only a few of the links were melted. In the case given of the Etna, the whole explosion seems to have been transmitted, without fusing the conductor. In the instance of the church struck by lightning at Kingsbridge, a short time since, it was observed, that the flash which rent the steeple, passed over a bell wire of about two-tenths of an inch diameter, without fusing it. In the case of the Plymouth church, the conductor was not fused; it was only disjointed. In the Transactions of the Royal Society for 1770, there is an instance of a bell wire having

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should have fallen on this building, capable of rendering a stout bar of iron, six inches wide, red-hot, and yet not have annihilated the thin gilding about the ball and cross, and without the crash of the thunder having been heard over the whole city—no mention of which is made. When St. Bride's steeple was struck, such was peculiarly remarkable. If however we admit the evidence, it is highly conclusive as to the value of lightning-conductors; since the former church of St. Paul's, not defended by a lightning-conductor, was twice struck by lightning, and much damaged: and it would also tend to show, that a flash of lightning, capable of rendering bars of iron, six inches wide, and one inch and a half thick, red-hot, could not fuse the small mass of thin copper covering the ball. The original ball and cross on which this lightning is said to have fallen, may be inspected at the Coliseum, London.

There is another case of the effects of lightning on an iron rod, in Port Royal, Jamaica, mentioned by Captain Dibdin, of a merchant vessel; and given in the Transactions of the Royal Society; the evidence of which is by no means complete. Two men are said to have been killed by a flash of lightning near a church wall:—on looking inside the wall, a bar of iron of an inch thick, and a foot long, was found to have been wasted away in many places, so as to be reduced in size to a fine wire; but it does not appear that the bar was examined before the lightning happened; so that we cannot infer that the lightning was the cause,—more especially as the appearance described is very common on bars of iron in church-yards in this country, and which has evidently been the result of oxidation and time.

[1] Priestley's History of Electricity.

conveyed a charge with safety, which knocked down a chimney, and did other damage; and in the same valuable work, for 1772, there is an instance of a bell wire having resisted fusion, in all the doubled or twisted portions. A house was struck at Tenterden, and the whole flash fell upon a bar of iron, three-fourths of an inch square; but produced no effect on it.[1] Mr. Calendrini was eye-witness to a flash of lightning which struck a bell wire, and was safely transmitted by it;[2] moreover, we never find that the vane spindles of ships become fused by lightning. It is very remarkable, when the conditions are favourable, how very small a quantity of metal is equivalent to transmit heavy electrical accumulations. In the great experiment of the French philosopher M. De Romas, an account of which will be found in Priestley's History of Electricity; the electric matter of a thunder-cloud was effectually discharged over a small wire, wove in the string of a kite; and which became sensible, by insulating the string. In this case, the electric fire "assumed the shape of a spindle, eight inches long, and five inches in diameter,"—another time, "streams of fire, which appeared to be an inch thick and ten feet long," were observed to dart into the ground, with a crashing noise similar to thunder, when very near.

29. Andrew Crosse, Esq. of Broomfields, near Taunton, a gentleman of high scientific attainment, has employed a very extensive atmospheric apparatus, from which similar effects have been witnessed. During the passage of a thunder-cloud, a full dense stream of sparks passes to the receiving ball, which at every flash of lightning is changed to an explosive stream, accompanied by a peculiar noise; and it has been well observed by Mr. Singer "that during this display of electric power, so awful to an ordinary observer, the electrician sits quietly in front of the apparatus, conducts the lightning in any required direction, and employs it to fuse wires, decompose fluids, or fire inflammable substances; and when the effects become too powerful to attend to such experiments, he then connects the insulated wire with the ground, and transmits the accumulated electricity in silence and safety."[3]

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[1] Trans. R. S. [2] Ibid.

[3] The authority of Professor Leslie has been quoted by some writers against lightning-conductors, but this eminent philosopher has two high a conception of

30. The utmost that can be urged in the shape of objection to the use of lightning-rods, is the circumstance of their constituting an easy line of discharge, so that the electric matter of a thunder-cloud may be imagined to fall upon a ship in consequence of such a line being present, when otherwise it would remain without a striking distance; but this, as already observed (22), is an objection purely hypothetical, and in no way deducible from experience, for although it is admitted that the discharge is greatly facilitated by the use of continuous conductors, and the electric action thereby more rapidly dissipated; yet it by no means follows, that without such conductors it would remain quiescent; the intense forces in operation in a thunder-storm exerted immediately from the earth's surface upon perhaps twenty or thirty thousand acres of electrified clouds, are never so nicely balanced as to be overset by the mere presence of a line of metal in a particular spot. The thunder-storm which occurred at Plymouth, on the 21st of May last,[1] is in point here; during the storm his Majesty's ship Caledonia, having fixed lines of metals in her three masts and bowsprit, was under sail in the Sound. The lightning struck very frequently in vivid and concentrated sparks immediately upon the surface of the sea, without approaching the ship, about the same time it struck repeatedly upon the distant hills, and split open some heavy masses of granite. In all these cases, therefore, it must never be forgotten, that the action extends over a vast surface, and that the immediate point, or points, in which the electric fluid strikes is rather dependent on the weaker state of the intervening insulating air, or on the forces exerted in such point or points (13), than on the presence of metallic substances projecting for a comparatively short distance into it: the attractive forces by which the discharges are occasioned being proportionate to the amount of the disturbance of the electrical distribution,

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great natural causes to reason in the confined way attributed to him. It is true, that from some very ingenious researches on the nature of electricity, he is led to believe that lightning-rods are not of great avail; but he considers them to be quite harmless, and observes, "that they *provoke* the shaft of heaven is the suggestion of *superstition* rather than of *science*."

[1] In the year 1831.

previously existing and being constantly in operation, whether the ship be present or not, or whether furnished with lightning-rods or not, as we have already shown by the above-mentioned cases (n) (o) (q) (r) (s).

31. Moreover, the mere discharge of an electrical accumulation will take place eventually to the same extent through the less perfect conductors as through metallic bodies, the difference being only in the rapidity of transmission (11). Thus a glass tube filled with water, or a pointed piece of wood, discharges a highly-charged electrical jar when placed near it, as effectually as a metallic rod, but not so rapidly; it is in fact from the slow transmission that the damage to the less perfect conductor so frequently ensues; the electric action not being equalized with such rapidity as to prevent its operation in an accumulated form; the more perfect the transmitting power, therefore, the less the chance of damage, as exemplified in the same instances (n) (o) (q) (r) (s).

32. The amount of what has been advanced concerning the operation of lightning-protectors is as follows:—Conductors of electricity remove, by the aptness of their parts, that resistance to the passage of the electric agency which it would otherwise experience; that consequently their action is purely passive; so that they can no more be said to attract or draw down the matter of lightning than a dyke can be said to attract the water which of itself finds its way through it: that such passive action cannot be fairly urged as an argument against lightning-rods, which operate only in conveying away the electric matter when it falls on them: that we must therefore make a great distinction between *lightning-attractors* commonly so called, and *lightning-protectors:* that inasmuch as all the materials of which a ship is composed are calculated to transmit electricity, and that detached masses of *metal are necessarily* found amongst them, and that too in a prominent way, such as studding-sail boom-irons, spindles, iron hoops, &c. &c. we have such passive attractors already present: that if we were even to remove them, the substances next in conducting power would supply their place (22); that finally the *continuous lightning-protector* is applied to prevent the mischief which always occurs when the electric matter finds its own way by main force (17).

Seeing therefore that we have no power to *avoid* or *resist* a stroke of lightning (23), it must be considered extremely fortunate that we have the power to control it. The best method of effecting this, will be the subject of another communication.

ART. XXXVIII.—*Conditions proposed by the French Minister of Marine, for a Public Competition for Plans for Circular Sterns to Line-of-Battle Ships and Frigates.* (From the Annales Maritimes.)

THE system of having the sterns of ships of a circular form, possesses the advantage of augmenting the strength of that part of a ship, and at the same time increasing its means of defence. In some of the sterns lately built on this principle, a plan has been adopted in which a part of the inconveniences of the old system are still retained; in others, the desire of rendering the stern ornamental, has caused the considerations of strength and defence to be lost sight of; in this case the adoption of the circular form for sterns, would possess inconvenience without utility, and essential advantages would be sacrificed to a foolish fancy for exterior decoration.

To counteract these errors, the minister of marine has instituted the following subject for public competition.

To furnish the best plans for the circular sterns for line-of-battle ships and frigates, with all the exterior and interior fittings, the manner of disposing the timbering so as to combine the necessary conditions for defence, with strength, lightness, a dispersion of the weight in proper proportion to the displacement of each part, the efficiency of the rudder, the convenience of the water-closets, and the general suitableness of the accommodations.

This manner of fitting the stern must possess facilities for enabling the commandant to be aware of whatever manœuvres may be in progress, without being obliged to appear on deck.

The style of ornament which it would be proper to adopt, as well for the forward as for the after parts of these new constructions, is also to be described. The competitors are to remember that nothing of importance is to be at all sacrificed to these decorations.

The side of the ship at the stern must have the same thickness as at the corresponding places in other parts of the ship. The ports must be so disposed, that it may be easy, on each deck, to bring guns to bear right aft, and on the angles of the quarters, to command those points which the other guns cannot be brought to bear upon.

The rudder may be fitted either without board, or within with a circular head, but reasons must be given for whichever plan may be proposed. Reasons also are to be stated for the station which may be proposed for the water-closets, whether they are fitted interiorly, or in an exterior gallery.

The officers of the different branches of the naval service are called upon to send their proposals to the minister before the 1st of July, 1832. Other persons wishing to become competitors, are eligible to do so.

The memoir in which each competitor explains his proposals, must be accompanied with all the calculations and drawings which may be necessary to render his plan perfectly complete, and intelligible in all its details.

Each proposal must have a motto affixed to it, of which a copy is to be enclosed in a sealed letter, containing also the name and place of residence of the proposer.

A medal of the value of 2000 francs will be given to the author of the best memoir presented to the Minister of Marine before the stated period.

Art. XXXIX.—*A List of the Patents which have been taken out since the* 1*st of January*, 1831, *for Inventions or Improvements connected with Naval Affairs.*

To John Revere, of Weybridge, in the county of Surrey, doctor of medicine, for a new and improved method of protecting iron chain cables, iron boilers, and iron tanks, from the corrosion produced upon them by the action of water Dated November 27th, 1830.

To William Church, of Haywood House, in the county of Warwick, esquire, for certain improvements in apparatus applicable to propelling boats and driving machinery by the agency of steam; parts of which improvements are also applicable to the purposes of evaporation. Dated November 29th, 1830.

To Samuel Brown, of Billiter-square, in the city of London, commander in the Royal Navy, for certain improvements in the means of drawing up ships and other vessels from the water on land, and for transporting or mooring ships, vessels, and other bodies on land, from one place to another. Dated December 6th, 1830.

To Richard Wilty, of Basford, in the parish of Wolstanton, in the county of Stafford, esquire, for certain improvements in apparatus for propelling carriages, boats, or vessels, and for other purposes, by the power of steam. Dated December 13th, 1830.

To Samuel Seaward, of the Canal Iron Works, in the parish of All Saints, Poplar, in the county of Middlesex, engineer, for an improvement or improvements in apparatus for economizing steam, and for other purposes, and the application thereof to the boilers of steam-engines employed on board packet-boats and other vessels. Dated January 15th, 1831.

To Andrew Smith, of Princes-street, Leicester-square, in the parish of Saint Martin's in the Fields, and county of Middlesex, engineer, for certain improvements in machinery for propelling boats and other vessels on water, and in the manner of constructing boats or vessels for carrying such machinery. Dated January 22d, 1831.

To William Peeke, of Torquay, in the parish of Tormsham, in the county of Devon, shipwright; and Thomas Hammick, of the same place, ship-smith, for certain improvements in rudder hangings and rudders for ships or vessels. Dated March 21st, 1831.

To John Wallace, of Leith, brazier, for an improvement or improvements upon the safety-hearth for the use of vessels. Dated March 31st, 1831.

END OF VOL. III.

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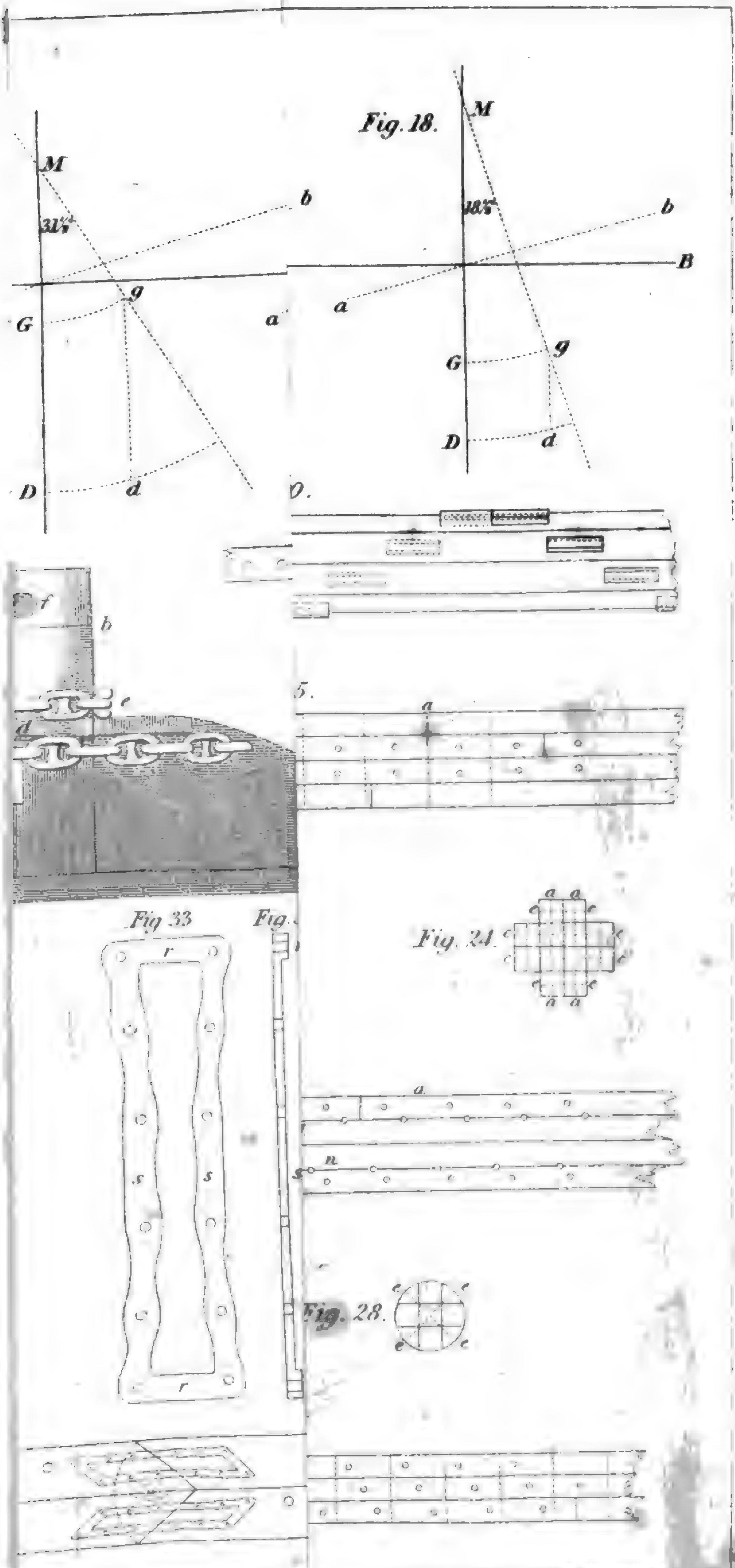
Pl. 2.



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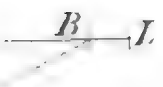
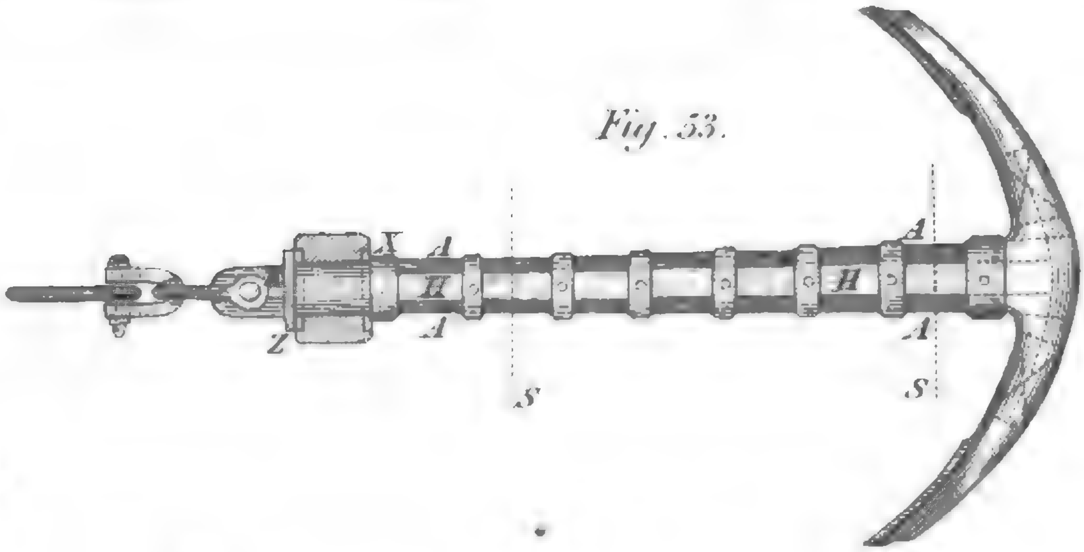
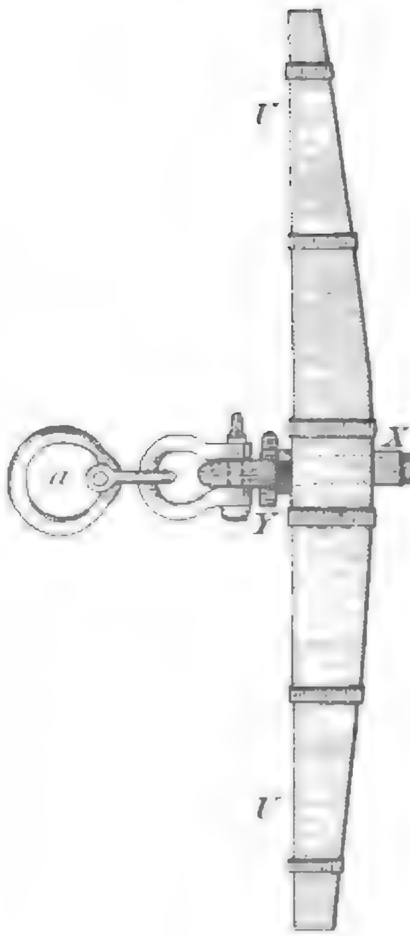


Fig. 53.





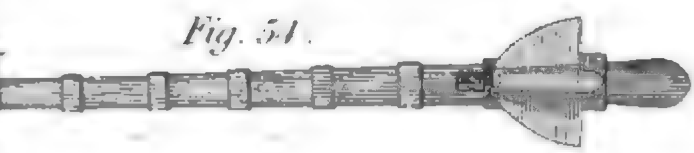
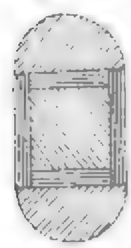


Fig. 54.

Fig. 56.



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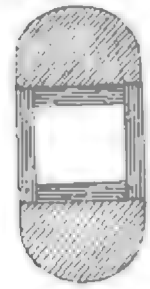


Fig. 49.

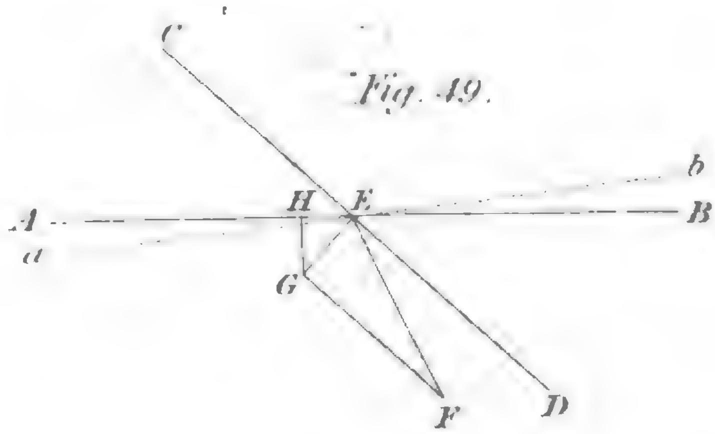


Fig. 52.

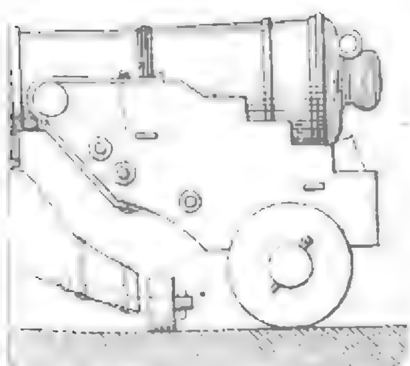
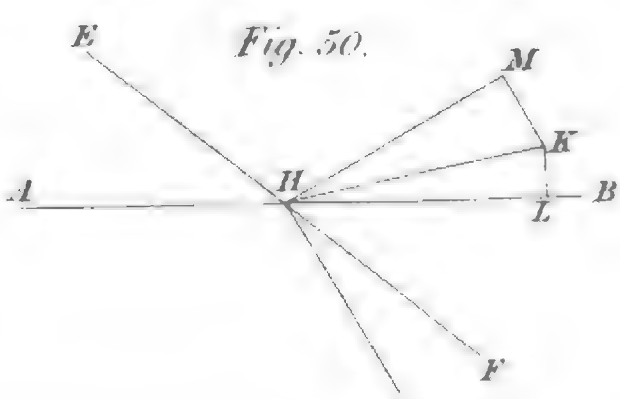


Fig. 50.



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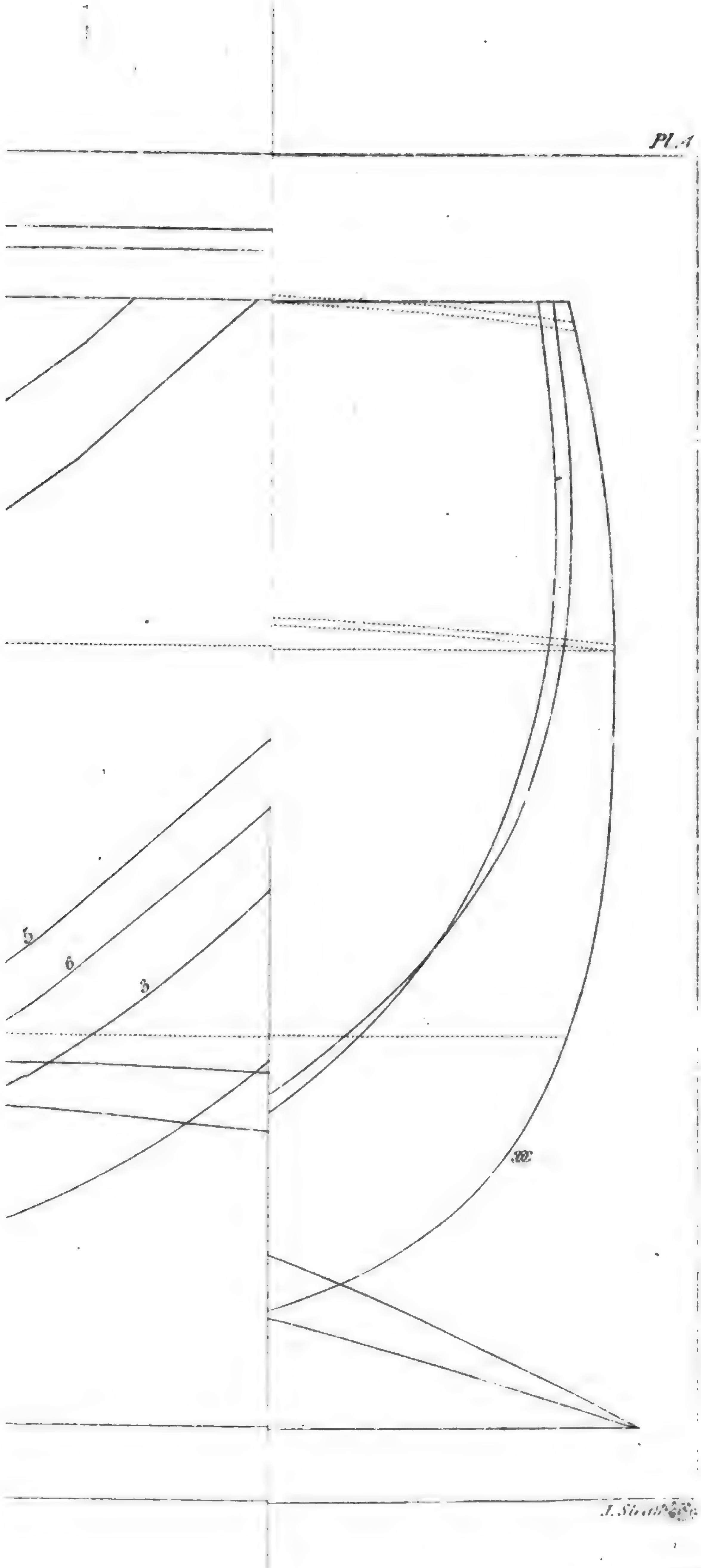
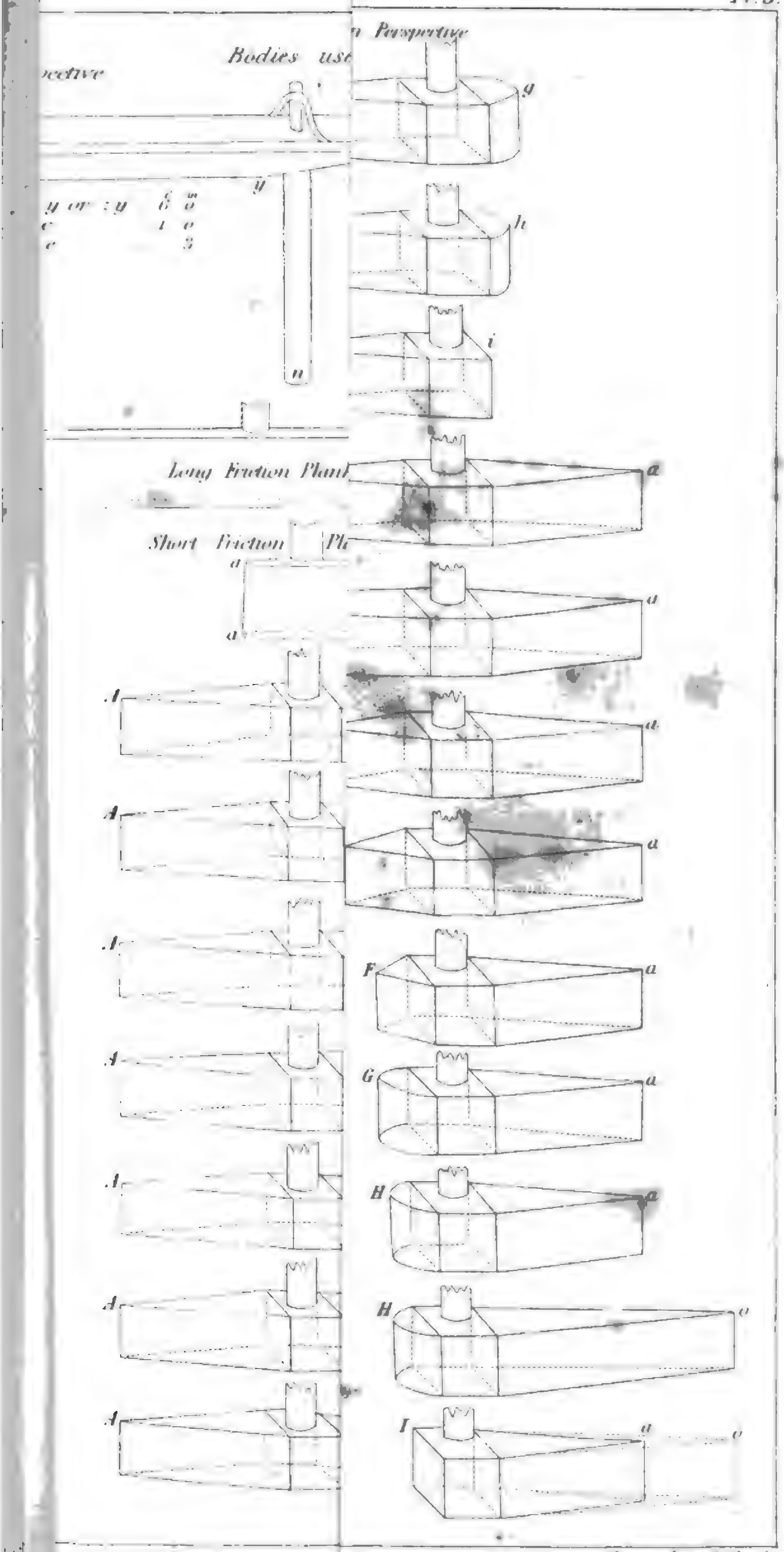
Pl. 1



Pl. 5.



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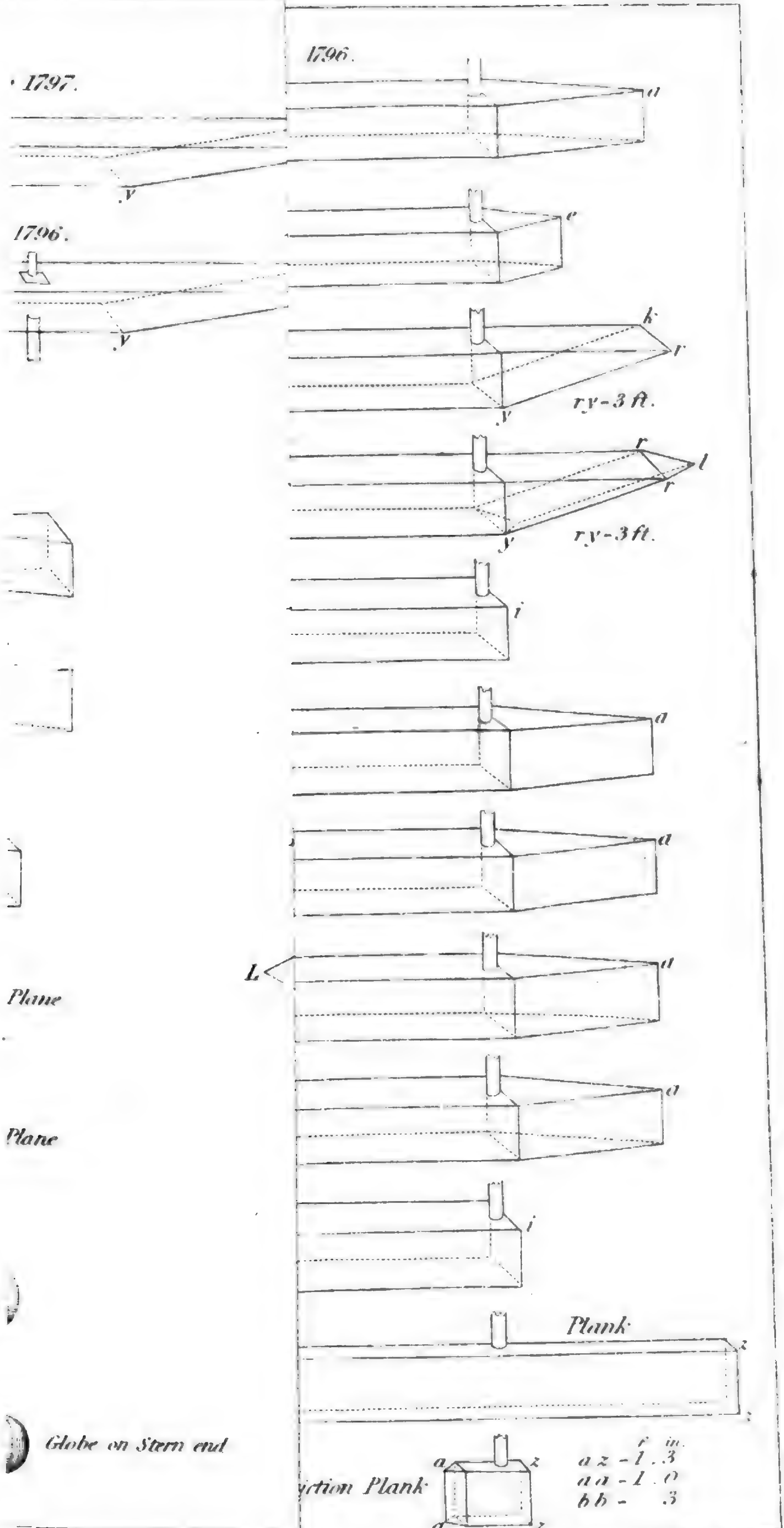
Pl. 6



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Pl. 7

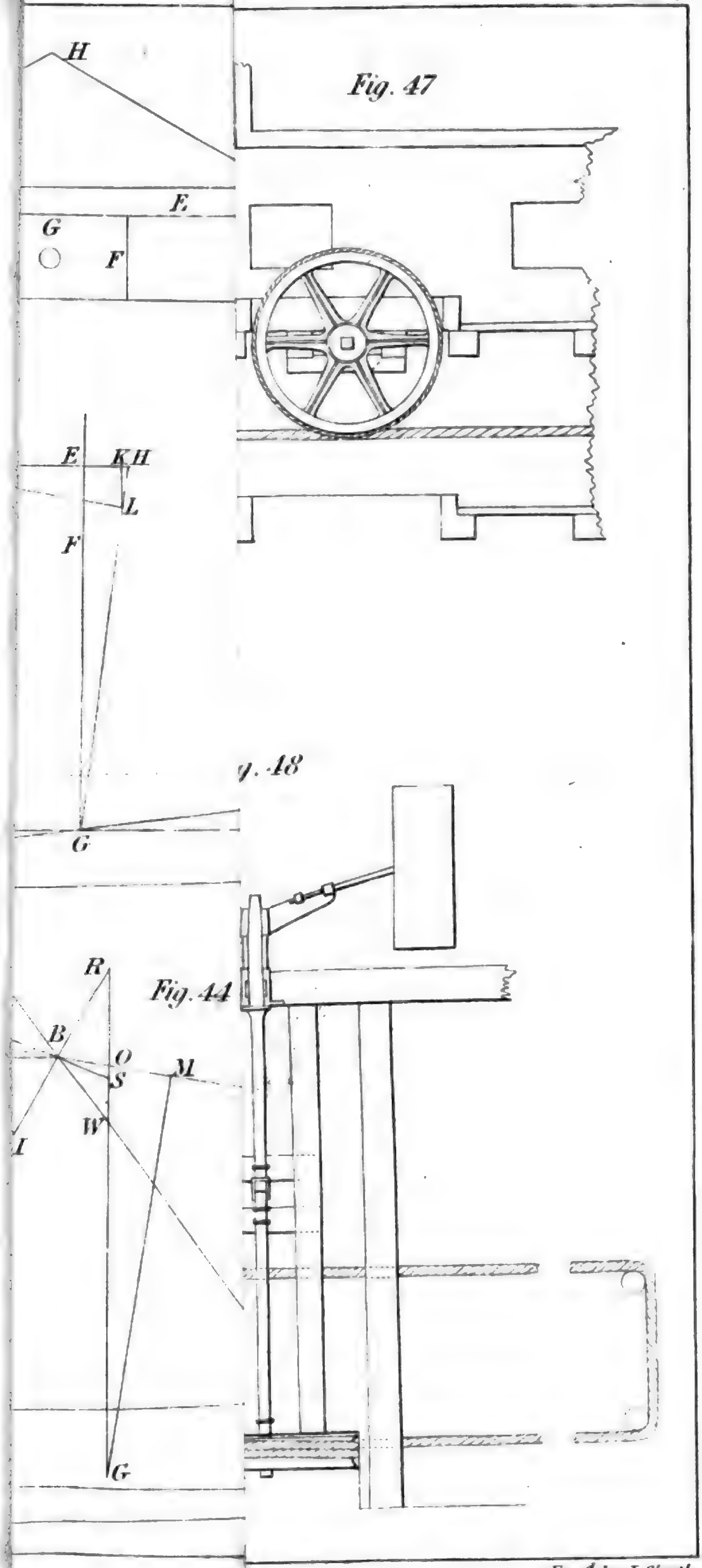

Fig. 47 ... Fig. 48 ... Fig. 44

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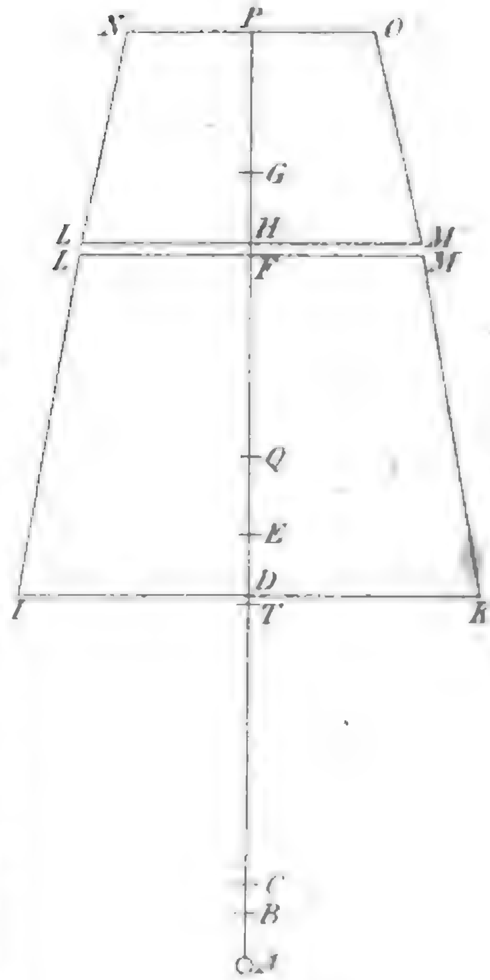
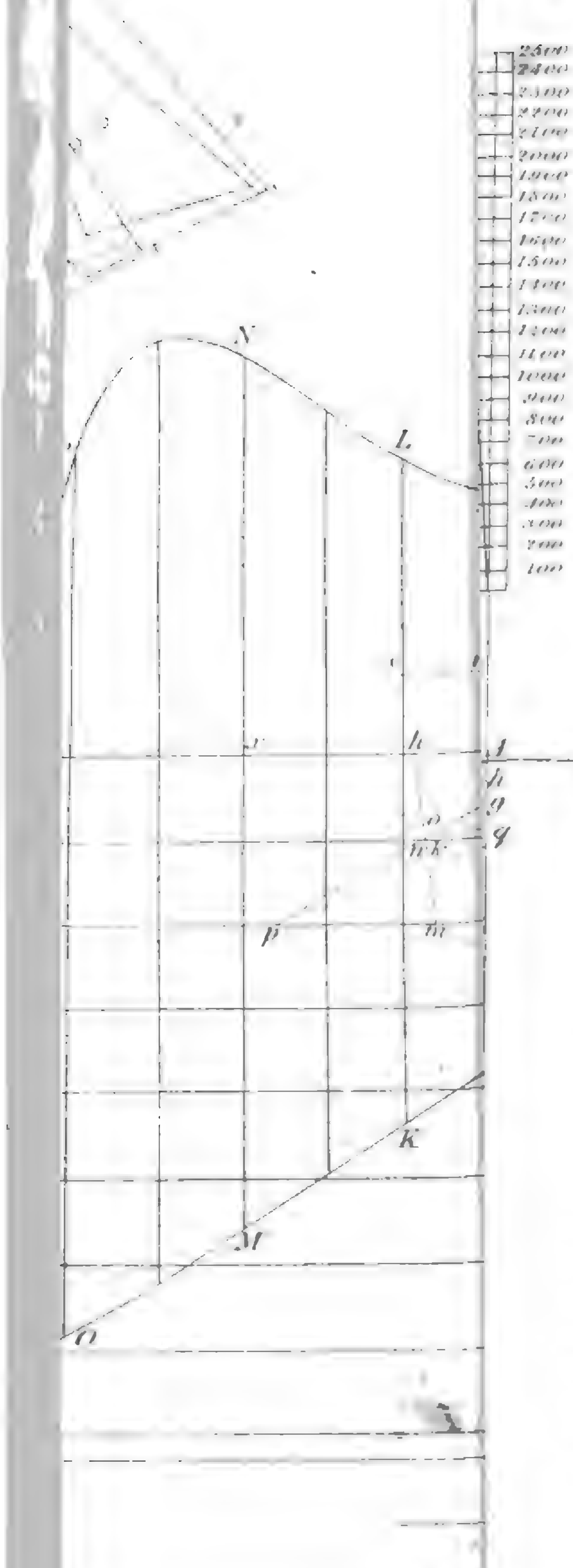
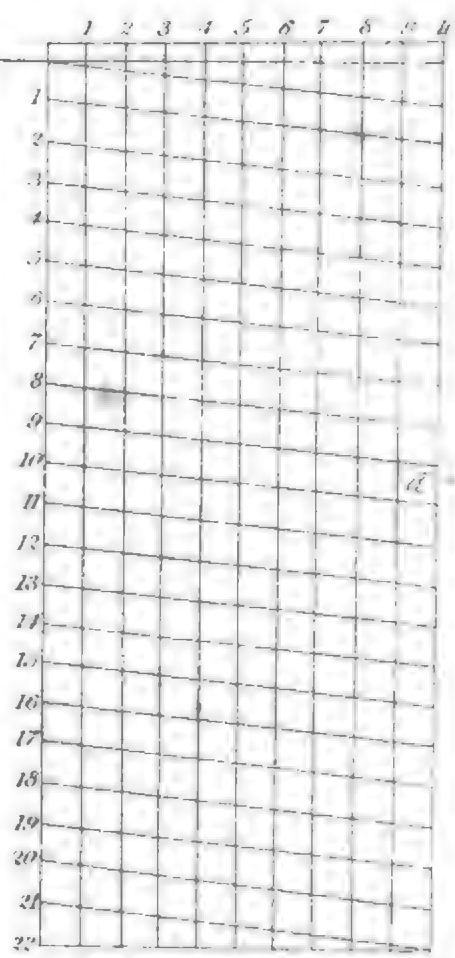
Pl. 8

Fig. 102.

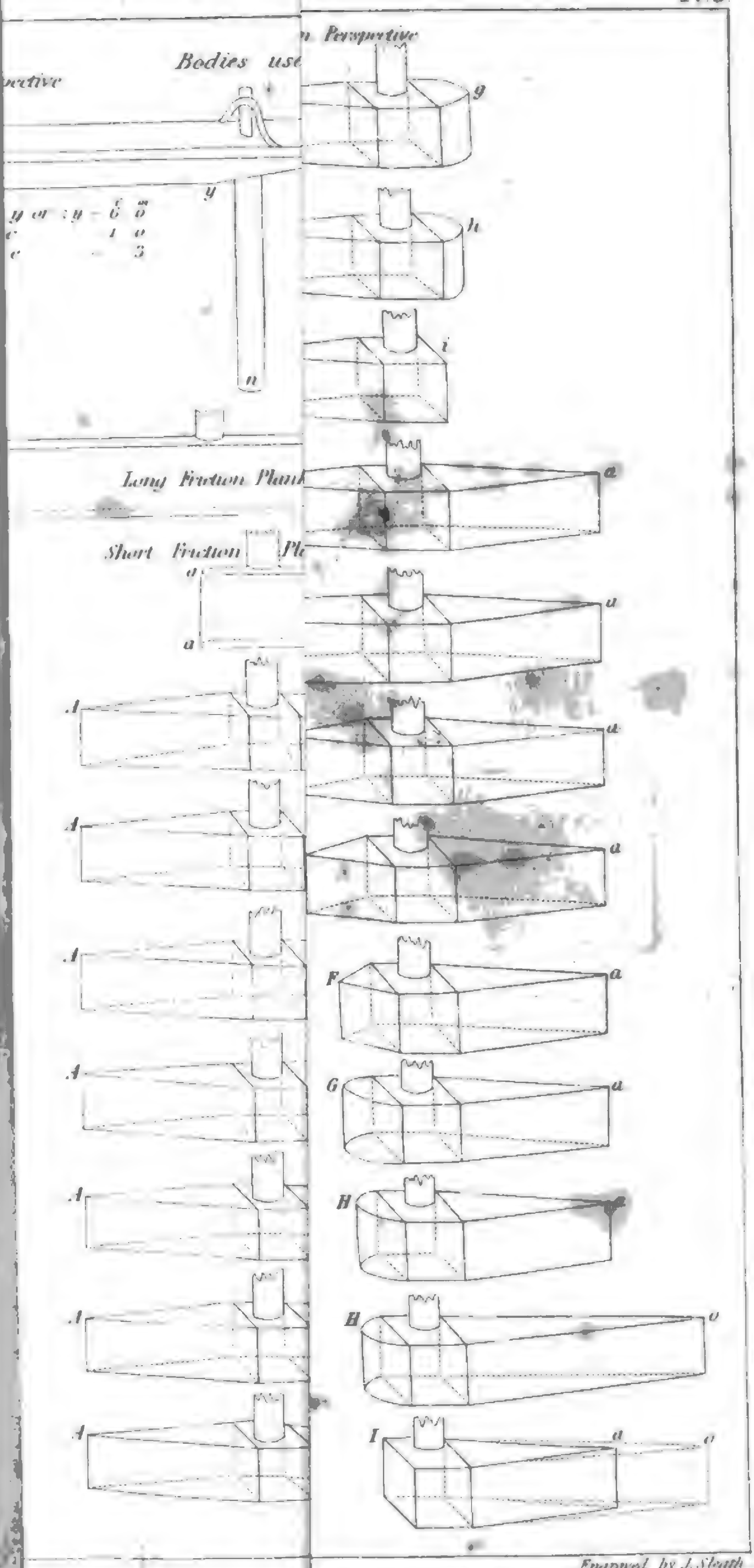






J. Sleath Sc.

Pl. 5.



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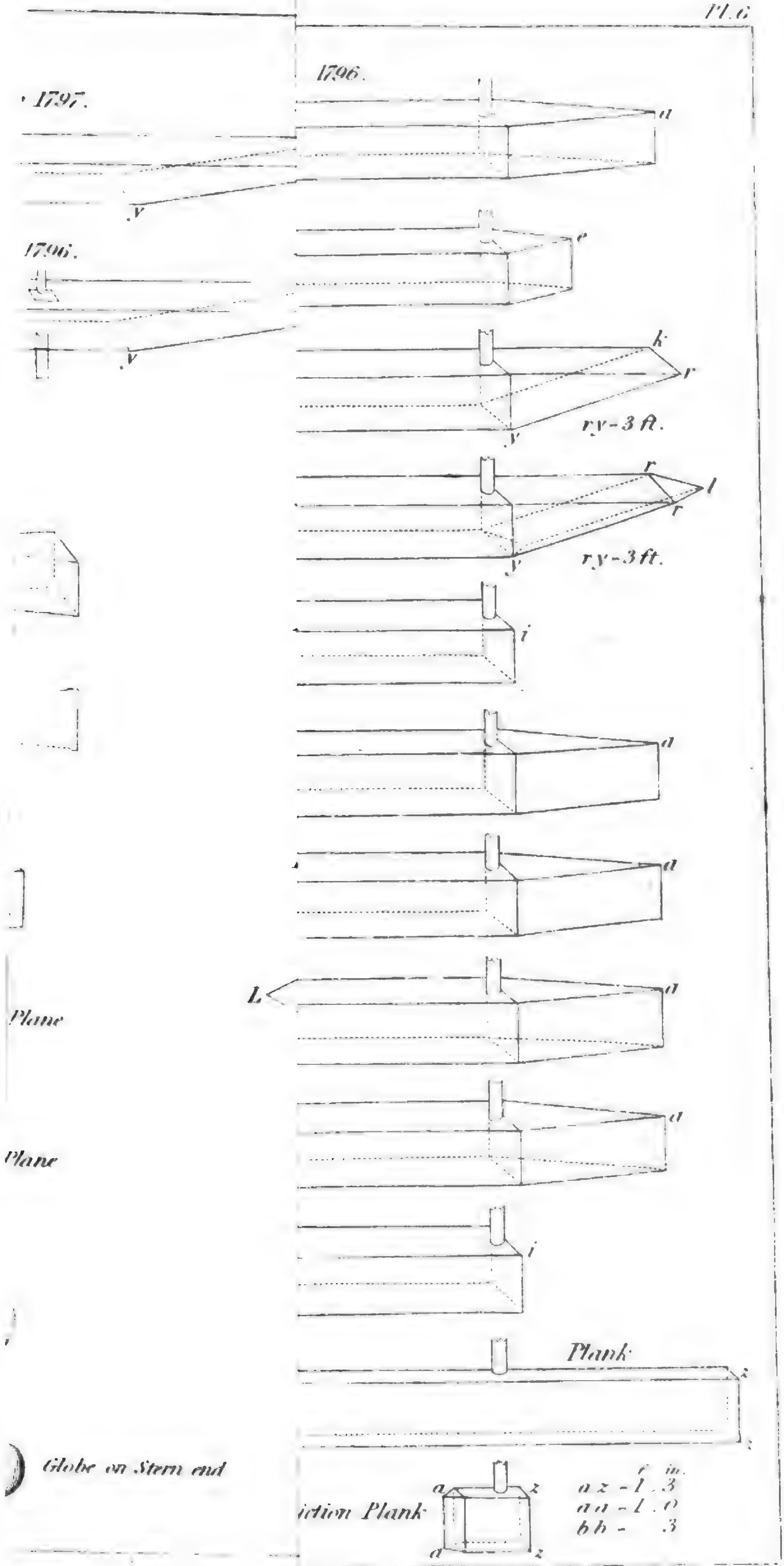
Pl. 6



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Pl. 7

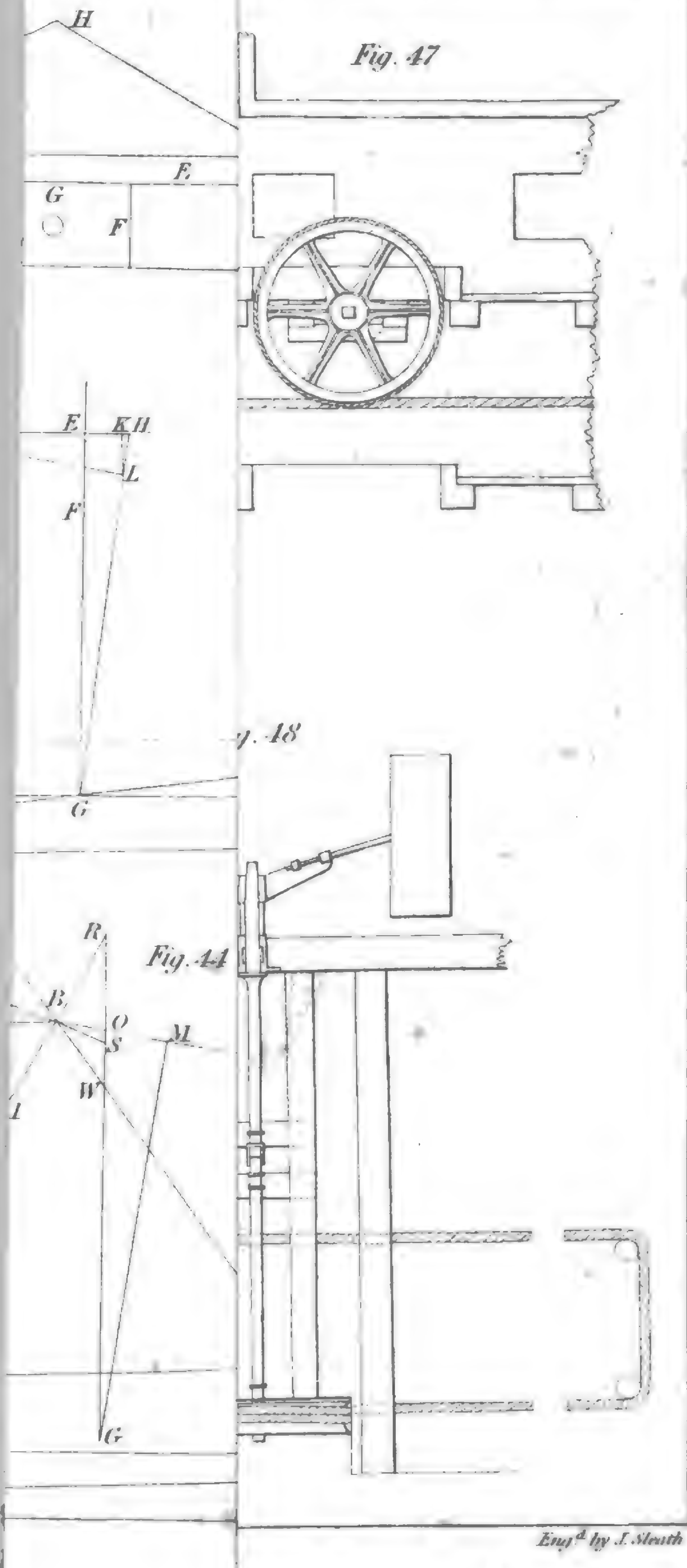


Fig. 47

...g. 48

Fig. 44

Eng^d by J. Sleath

Pl. 8

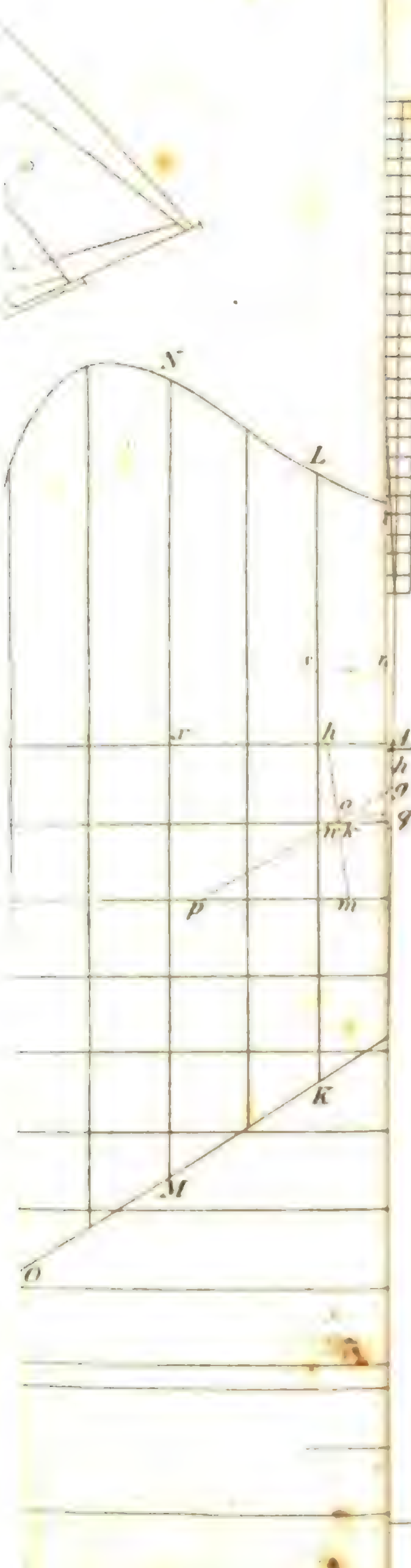
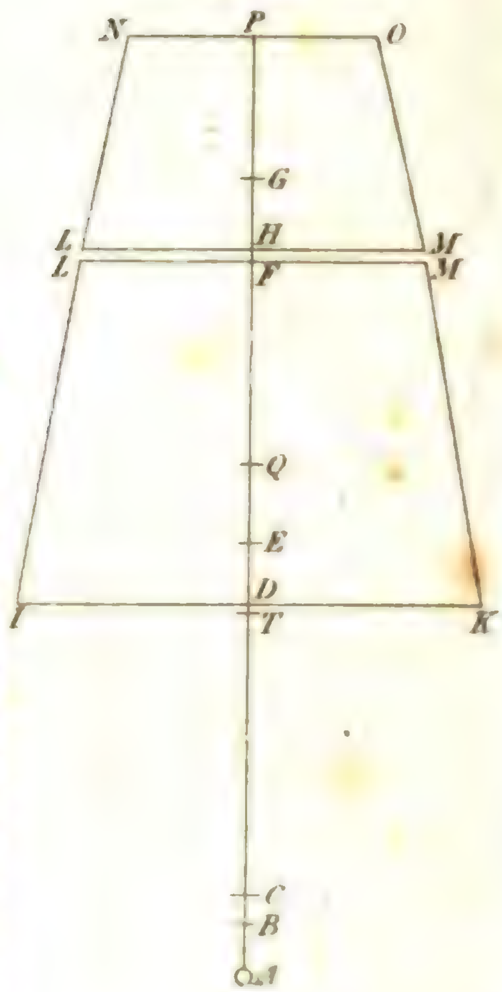
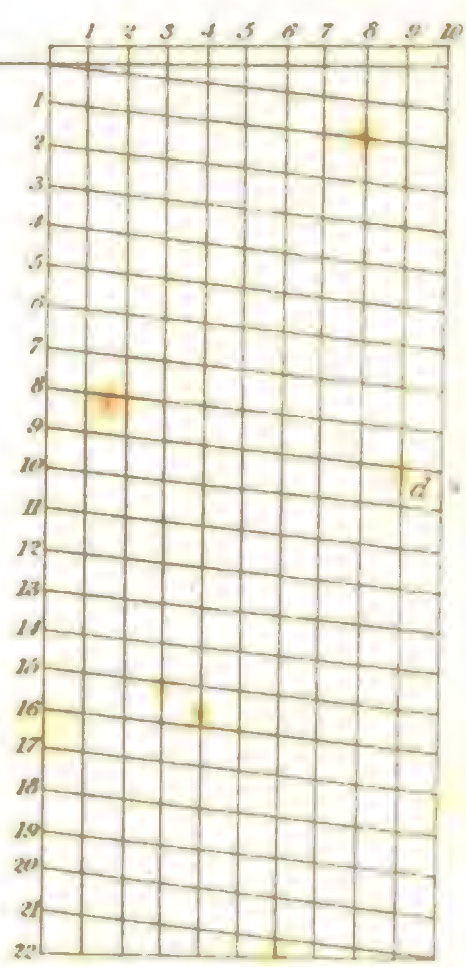
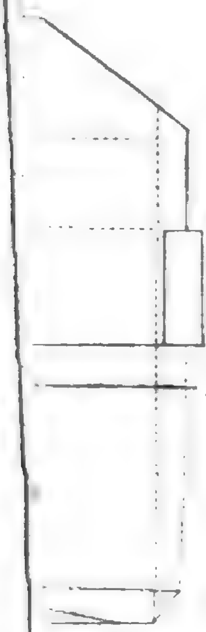


Fig. 102.





J. Sleath Sc.



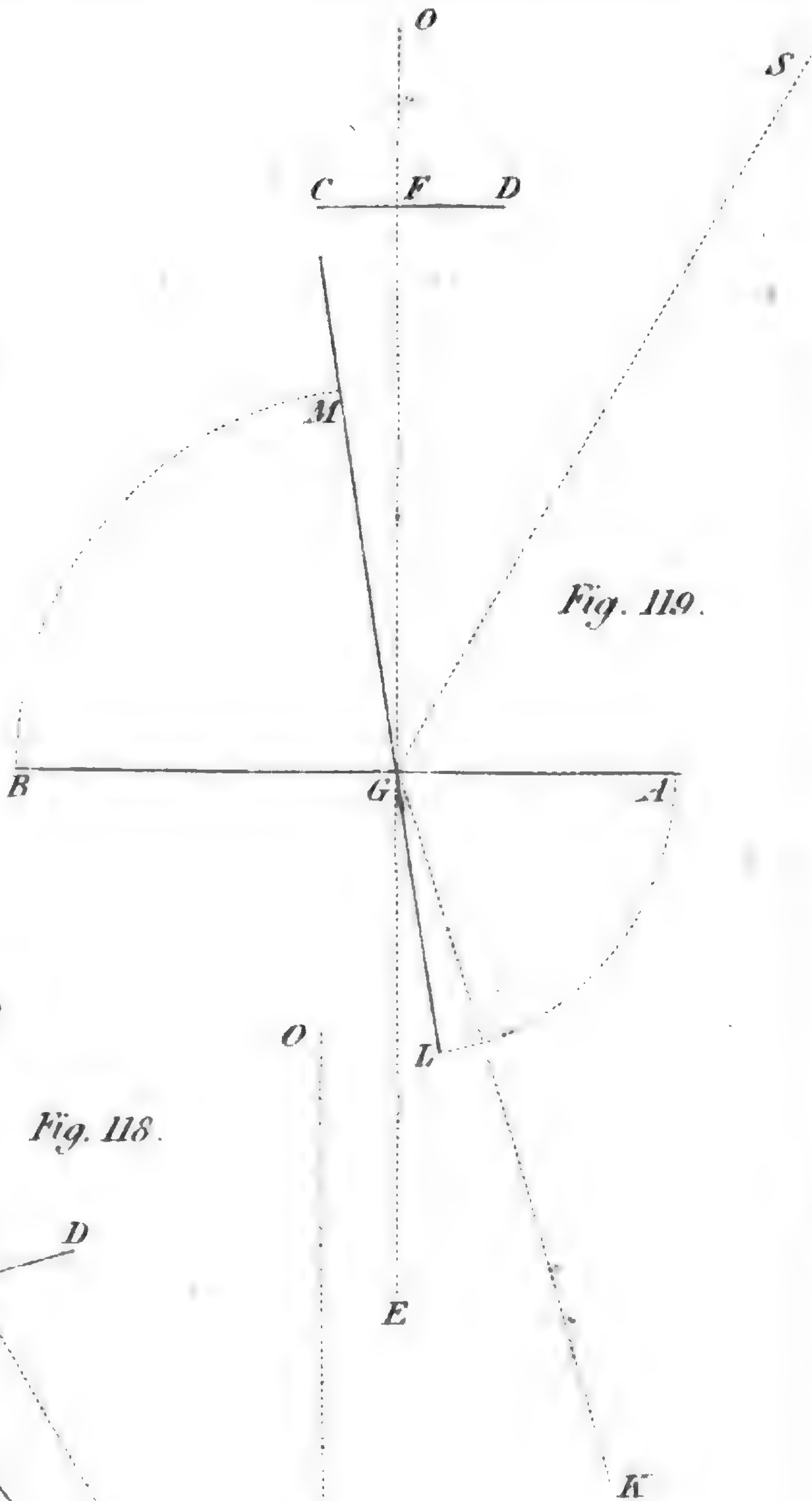


Fig. 119.

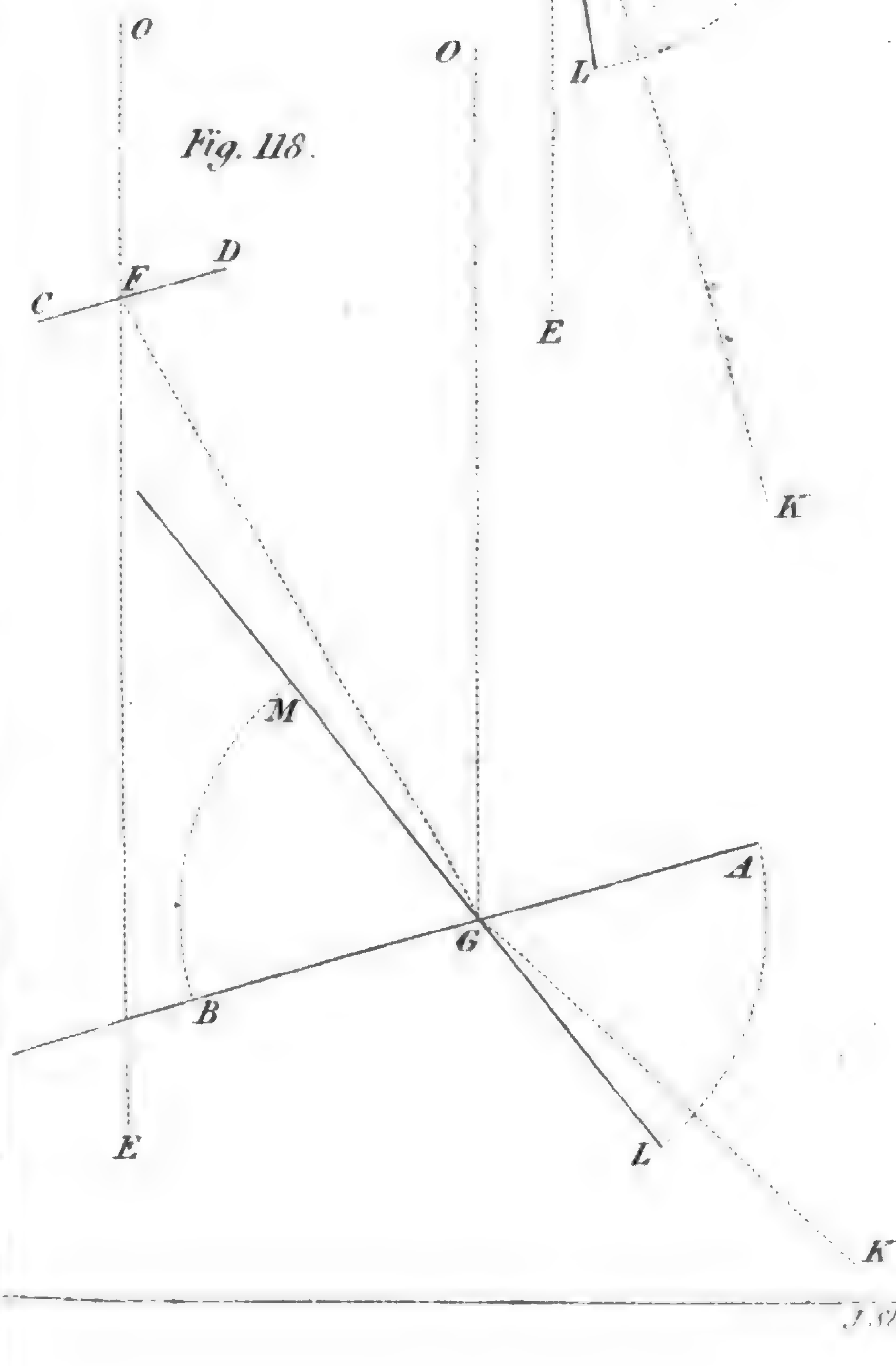


Fig. 118.

PAPERS

ON

NAVAL ARCHITECTURE,

AND OTHER SUBJECTS CONNECTED WITH

NAVAL SCIENCE.

CONDUCTED BY

WILLIAM MORGAN AND AUGUSTIN CREUZE,

NAVAL ARCHITECTS, FORMERLY STUDENTS AT THE SCHOOL OF NAVAL ARCHITECTURE IN HIS MAJESTY'S DOCK-YARD AT PORTSMOUTH.

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CONTENTS

OF

No. XIII.

PAPERS

ON

NAVAL ARCHITECTURE,

&c.

ARTICLE I.—*Chapman's Work on Ships of War, translated from the Swedish, by* WM. MORGAN, *of His Majesty's Dock-yard at Sheerness.*—(Continued from page 388, vol. 3.)

CHAP. XVI.

51. THE parabolic method of construction will be now applied to the construction of frigates, as it has been to ships of the line; namely, of a frigate of 40 guns, one of 32, and another of 20 guns, also of a brig of 8 guns. The determination of the displacements will be found further forward in this work, where general rules are given for a greater number of frigates, according to the parabolic method of construction. Likewise a frigate of 52 guns will be inserted first in the Tables, formed according to the same method. The most important elements which are necessary in the construction of these vessels are found in the following Table. For the proportions of the frigate of 52 guns, which are marked *, the rules inserted have not been used.

Table No. 39.

	52	40	32	20	8
Displacement $= D$	66753*	46877	30434	20162	3821
Length of the water-line of construction $= 4{,}1809 . D^{\frac{1}{3}} = l$	166,00*	150,75	130,53	113,80	65,38
Increase forward $= 1{,}75$, and abaft $= 1{,}0$, $= f$	2,75	2,75	2,75	2,75	2,75
$l + f = L$	168,75	153,50	133,28	116,55	68,13
Breadth at the water-line $\frac{l^{0,8057}}{1{,}4063} = B$	45,00*	40,46	36,02	32,25	20,64
Depth of the ⊕ section to the keel $= 0{,}1023 . L$ [illegible]	17,60*	15,70	13,63	11,92	6,97
$1{,}6491 . D^{0,0293} = n$	2,33*	2,26	2,232	2,205	2,1
Depth of the line of sections at the ⊕ section $= \frac{\overline{n + 1} . D}{n\, l\, B} = \mathbf{h}$	12,771	11,087	9,373	7,985	4,183
Area of the ⊕ section $= \mathbf{h} . B = \oplus$	574,71	448,55	337,62	257,52	86,34
Centre of gravity before the middle of $L = \frac{L}{80}$	2,11	1,919	1,666	1,457	0,852
Centre of gravity before the middle of $l = \mathrm{a}$	2,485	2,294	2,041	1,832	1,227
⊕ section before the middle of the water-line of construction $l = \mathrm{a} . \overline{n + 2}$	10,76	9,772	8,64	7,770	5,03
Depth of ⊕ section of construction $= \frac{D^{0,3417}}{2{,}63} = d$	16,93	15,00	12,94	11,24	6,37
From the ⊕ section to the fore-end of l	72,24	65,60	56,62	49,20	27,66
From the ⊕ section to the after-end of l	93,76	85,15	73,91	64,60	37,72
Height of battery	6,33	8,23	7,25	6,33	4,00

TABLE No. 40.

Calculations of the ordinates h of the line of sections (according to the equation $x = \frac{y^n}{p}$), and thence the areas of the sections and the ordinates C of the ribband-line.

Double Frigate of 52 guns.

Ordinate y	$\frac{y^{2,33}}{16,74} = x$	Ordinates of line of sections $\mathbf{h} - x = h$	Half areas of sections $\frac{1}{2} B . h = 22,5 . h$	Ordinates C of ribband-line. Forward.	Ordinates C of ribband-line. Abaft.
10	12,771	0,000	0,00	—	—
9	9,991	2,780	62,55	4,90	4,29
8	7,593	5,178	116,50	7,15	6,58
7	5,563	7,208	162,18	8,80	8,34
6	3,885	8,886	199,94	10,07	9,72
5	2,540	10,231	230,20	11,03	10,80
4	1,510	11,261	253,37	11,75	11,61
3	0,773	11,998	269,34	12,25	12,18
2	0,300	12,471	280,60	12,57	12,54
1	0,060	12,711	286,00	12,73	12,72
⊕	0,000	12,771	287,36	12,771	12,771

Forward

$C = 0,333\ h + 0,667 \sqrt{\mathbf{h}\ h}$

Abaft

$C = 0,525\ h + 0,475 \sqrt{\mathbf{h}\ h}$

Frigate of 40 guns.

Ordinate y	$\frac{y^{2,26}}{16,414} = x$	Ordinates of line of sections $\mathbf{h} - x = h$	Half areas of sections $\frac{1}{2} B . h = 20,23\ h$	Ordinates C of ribband-line. Forward.	Ordinates C of ribband-line. Abaft.
10	11,086	0,000	0,00	0,00	0,00
9	8,737	2,349	47,54	4,28	3,66
8	6,695	4,391	88,84	6,21	5,62
7	4,951	6,135	124,12	7,62	7,14
6	3,495	7,591	153,58	8,70	8,34
5	2,315	8,771	177,45	9,54	9,29
4	1,398	9,688	196,00	10,16	10,01
3	0,730	10,356	209,51	10,61	10,53
2	0,292	10,794	218,37	10,90	10,86
1	0,061	11,025	223,05	—	—
⊕	0,000	11,086	224,27	10,086	11,086

For this and the following at the 7th section.......... $C = 1,3406 . h^{0,958}$ forward; $C = 1,2401\ h$^[illegible] abaft

Forward

$C = 0,297\ h + 0,703 \sqrt{\mathbf{h}\ h}$

Abaft

$C = 0,524\ h + 0,476 \sqrt{\mathbf{h}\ h}$

TABLE No. 40.—(*continued.*)

Frigate of 32 guns.						Frigate of 20 guns.					
Ordinate y	$\frac{y^{2,232}}{18,202}=x$	Ordinates of line of sections $\mathbf{h}-x=h$	Half areas of sections $\frac{1}{2}B.h=$ 18,01. h	Ordinates C of ribband-line. Forward.	Ordinates C of ribband-line. Abaft.	Ordinate y	$\frac{y^{2,205}}{20,078}=x$	Ordinates of line of sections $\mathbf{h}-x=h$	Half areas of sections $\frac{1}{2}B.h=$ 16,125 h	Ordinates C of ribband-line. Forward.	Ordinates C of ribband-line. Abaft.
10	9,373	0,000	0,00	0,00	0,00	10	7,985	0,000	0,00	0,00	0,00
9	7,409	1,964	35,37	3,64	3,10	9	6,330	1,655	26,69	3,11	2,65
8	5,696	3,677	66,22	5,25	4,75	8	4,882	3,103	50,04	4,48	4,04
7	4,228	5,145	92,66	6,44	6,02	7	3,637	4,348	70,11	5,48	5,12
6	2,997	6,376	114,83	7,35	7,04	6	2,589	5,396	87,01	6,25	5,98
5	1,995	7,378	132,88	8,05	7,84	5	1,736	6,249	100,77	6,85	6,66
4	1,213	8,160	146,96	8,58	8,45	4	1,059	6,926	111,68	7,30	7,18
3	0,638	8,735	157,32	8,96	8,89	3	0,561	7,424	119,71	7,63	7,56
2	0,258	9,115	164,16	9,21	9,18	2	0,230	7,755	125,05	7,84	7,81
1	0,055	9,318	167,82	9,34	9,33	1	0,050	7,935	127,95	7,95	7,95
⊕	0,000	9,373	168,81	9,37	9,37	⊕	0,000	7,985	128,76	7,985	7,985
Forward $C=0,2807.h+0,7193\sqrt{\mathbf{h}\,h}$			Abaft $C=0,5109.h+0,4891\sqrt{\mathbf{h}\,h}$			Forward $C=0,267.h+0,731\sqrt{\mathbf{h}\,h}$			Abaft $C=0,499.h+0,501\sqrt{\mathbf{h}\,h}$		

TABLE No. 40.—(*continued.*)

Brig of 8 guns.					
Ordinate y	$\frac{y^{2,1}}{30,096}=x$	Ordinates of line of sections $\mathbf{h}-x=h$	Half areas of sections $\frac{1}{2}B.h=10,32.h$	Ordinates C of ribband-line. Forward.	Abaft.
10	4,183	0,000	0,00	0,00	0,00
9	3,353	0,830	8,57	1,64	1,40
8	2,618	1,510	15,58	2,30	2,06
7	1,978	2,205	22,76	2,86	2,66
6	—	—	—	—	—
5	0,976	3,207	33,10	3,56	3,46
4	—	—	—	—	—
3	0,334	3,849	39,72	3,98	3,94
2	—	—	—	—	—
1	—	—	—	—	—
⊕	0,000	4,183	43,17	4,183	4,183
Forward $C=0,213.h+0,787\sqrt{\mathbf{h}\,h}$			Abaft $C=0,453.h+0,547\sqrt{\mathbf{h}\,h}$		

The drawings which are constructed according to these calculations are found in plates XX, XXI, XXII, XXIII, and XXIV. Each frigate has two plates with the same number. The sheer-draughts are marked *A*, and the body-plans *B*.

The measurements are then taken from these drawings, and their results inserted in the following Table.

TABLE No. 41.

	52	40	32	20	8
Displacement $= D$	66788	46862	30498	20221	3817
Centre of gravity before middle of water-line of construction l	2,451	2,254	2,053	1,815	1,258
Ditto before middle of water-line L..	2,076	1,869	1,678	1,440	0,883
Half area of upper water section $=W$	3196	2582	1988	1536	539,4
$\frac{\int \frac{2}{3} y^3\,dx}{D}=p$	13,54	12,454	11,639	10,767	7,868
Centre of gravity of displacement below upper water-line $= g$	6,22	5,459	4,66	4,022	2,263
Metacentre above water-line $p-g=e$	7,32	6,995	6,979	6,745	5,605

52. From the calculations of the effect of the water in opposing the motion of the two frigates of 40 guns, the one constructed by the relaxation-line and the other by the parabolic method, it is found, that on the former the resistance of the water forward is = 2459,7, and the force of cohesion abaft is = 345,49, the sum of which is = 2805,19; and on the latter the resistance of the water forward is = 2405, and the force of cohesion abaft is = 470,92, the sum of which is = 2875,92. Consequently, if the little difference of the resistances on the bows of these two ships is neglected, so that they may be considered equal, then the excess arising from the inequality of the force of cohesion abaft, is on the whole not more by the parabolic method, than about one-twentieth part of the greater resistance.

That the application of the relaxation-line does not conduce more to fast sailing, may be inferred, it appears, from what follows.

With a new frigate of 40 guns, in which the relaxation-line was so applied that it should produce the greatest effect possible in diminishing the force of the cohesion of the water abaft, an experimental cruise was made last summer, 1803, under my inspection, in the Baltic; and I let some trials be made, in an ordinary and steady topsail breeze and in smooth water close-hauled, but not nearer to the wind than from 7 to $6\frac{1}{2}$ points, and sailing at about 9 knots; I gave the frigate a greater or less difference of draught of water, by a certain quantity of pig-ballast, which was placed for the occasion in midships on the orlop deck. It was found by a constant use of the log-line, that its velocity was something greater, when it sailed at the water-line drawn on the draught, than when it had more or less difference of draught of water, which confirms the truth of the theory; but when tried in a high sea there was no difference in the velocity. It should likewise be remarked, that this frigate was not coppered, which certainly increased the difference; but in all cases it should be concluded, that the form which is produced by the application of the relaxation-line, in respect to fast sailing, is of little consequence, and that its application to the construction of ships may be omitted; but the method of calculating the effect of the water in op-

posing the course of a ship, will, nevertheless, in all respects remain the same, and more especially, as it cannot be omitted in the formation of a ship of the line.[1]

53. The frigates inserted in the foregoing section 51, are given as examples of construction by the parabolic method; but as there are many different services for which frigates are required, a considerable number are inserted in the following table, some of which it is presumed will be found there adapted to the purpose; but if vessels of any other kind of armament, &c. than are given in this table, are required, all their proportions can be obtained from the given expressions; and the same method of construction can be used for all ships and vessels, of any magnitude and intended for any purpose. A parallelopiped will in the first place be formed, for these vessels as for ships of the line, from the displacement, and thence the parabolic element; the rest follows in the same order.

---

[1] What is observed about the middle of the 8th section on the resistance of the water on bodies, in the "Transactions of the Royal Academy of Sciences," must not be neglected to be remarked, namely, "That the water on the windward side of the after part of a ship, has a considerable effect in bringing a ship up to the wind, &c." which was experienced in the ardency of the just-mentioned frigate of 40 guns, which arises partly from the diminution of the force of cohesion.

TABLE No. 42.

Frigates and smaller armed Vessels.

	44		40	
	No.	Pounder.	No.	Pounder.
Guns on deck	26	30	26	24
Guns on quarterdeck and forecastle	18	12	14	8
Crew = m	400		330	
Number of months for which provisioned = M	5		5	
Guns, &c. and ammunition for 60 rounds per gun in cubic feet of water.	6275		4819	
Weight of crew with their effects, at 4 cubic feet each	1600		1320	
Provisions and tare; wood for a month; water and tare for half that time, at 4,767 cubic feet per man = $4{,}767.m.M$ =	9534		7865	
Ballast	5650		4649	
Total = S	23059		18653	
Weight of vessel itself = $1{,}2265.S$	28282		22878	
Mast and yards, boats, galley, cordage and rigging, sails, anchors, cables and hawsers, blocks, dead-eyes, master's and carpenter's stores, &c. = $1{,}0192.S^{0{,}871}$	6431		5346	
Total displacement = D.	57772		46877	
Length of the water-line of construction = $4{,}1809\,D^{\frac{1}{3}} = l$	161,63		150,75	
Increase forward = 1,75; abaft = 1,0 = f	2,75		2,75	
Whole length of water-line between rabbets = $l + f = L$.	164,38		153,50	
Greatest breadth at the water-line = $\frac{l_{0{,}7884}}{1{,}2892} = B$	42,74		40,46	
Depth of the parallelopiped $\frac{D}{l\,B} = t$	8,3630		7,6856	

TABLE No. 42.—(*continued.*)

	36	32	28	24	20	16	14	12	10	8
	No. Pdr.	No. Pdr.	No. Pdr.	No. Pdr.	No. Pdr.	No. Pdr.	No. Pdr.	No. Pdr.	No. Pdr.	No. Pdr.
Guns on deck	24 18	24 12	22 12	20 12	20 12,l.w.	16 8	14 6	12 6,l.w.	10 4	8 4,l.w.
Guns on quarterdeck and forecastle	12 6	8 6,l.w.	6 4	4 4,l.w.	—	—	—	—	—	—
m	278	238	213	194	179	149	115	86	52	32
Number of months, &c. M	5	5	$4\frac{1}{4}$	$4\frac{1}{2}$	$4\frac{1}{3}$	4	4	4	4	4
Guns, &c.	3351	2325	1997	1756	1473	923	611	433	285	196
Weight of crew, &c.	1112	952	852	776	716	596	460	344	208	128
Provisions and tare, &c. $4,767 . m\ M$	6626	5672	4822	4162	3697	2841	2192	1640	991	610
Ballast	3756	3081	2492	2258	2031	1548	1210	944	750	523
S	14845	12030	10163	8952	7917	5908	4473	3361	2234	1457
$1,2265 . S$	18207	14755	12465	10980	9710	7246	5486	4122	2740	1787
Masts and yards, &c. $= 1,0192 . S^{0,871}$	4382	3649	3150	2821	2535	1964	1541	1202	842	580
D	37434	30434	25778	22753	20162	15118	11500	8685	5816	3824
l	139,86	130,53	123,51	118,47	113,79	103,38	94,37	85,94	75,19	65,38
	2,75	2,75	2,75	2,75	2,75	2,75	2,75	2,75	2,75	2,75
L	142,61	133,28	126,26	121,22	116,54	106,13	97,12	88,69	77,94	68,13
B	38,14	36,12	34,58	33,46	32,413	30,05	27,97	25,98	23,38	20,94
t	7,0177	6,4551	6,0356	5,7399	5,4670	4,8665	4,3568	3,8899	3,3084	2,7932

TABLE No. 42.—*(continued.)*

	44	40
Abscissa of the line of sections, or its depth at $\oplus$ section $= 1{,}51144 \,.\, t^{0{,}9771} = \mathbf{h}$	12,040	11,0862
Exponent of the line of sections $= \frac{t}{\mathbf{h} - t} = n$	2,2744	2,2600
Area of $\oplus$ section $= B \,.\, \mathbf{h} = \oplus$	514,60	448,55
Depth of $\oplus$ section of construction $= 1{,}8041\, \mathbf{h}^{0{,}8804} = d$	16,130	15,000
Depth of $\oplus$ section to upper side of rabbet of keel $= 1{,}2018 \,.\, d^{0{,}949} = q$	16,82	15,70
Exponent of $\oplus$ section $= \frac{\oplus}{B\,d - \oplus} = m$	2,9439	2,8327
Half area of water-line $= \frac{\overline{\frac{1}{2} B\, L}^{\,1{,}0553}}{1{,}8761} = W$	2940,8	2582,0
Exponent of water-line $= \frac{W}{\frac{1}{2} B\, L - W} = r$	5,1413	4,9341
Moment $\frac{\overline{\overline{\frac{1}{2} B}^{2} .\, W}^{\,1{,}019}}{2{,}3564} = \int \frac{2}{3} y^3\, d\,x$	745176	583650
From centre of gravity of displacement to metacentre $= \frac{\int \frac{2}{3} y_3\, d\,x}{D} = p$	12,899	12,450
Exponent of displacement, calculated from the water-line downwards $\frac{\frac{1}{2} D}{d\, W - \frac{1}{2} D} = s$	1,5573	1,5327
Centre of gravity of displacement below water-line $= \frac{\overline{s+1} \,.\, \overline{2s+1} + s \,.\, \overline{2s+4} \,.\, d}{2 \,.\, \overline{2s+1} \,.\, \overline{2s+4}} = g$	5,9514	5,5159
Metacentre above water-line $= p - g = e$	6,948	6,934
Common centre of gravity of ship above water-line $= v$	2,400	2,300
Distance between the metacentre and this centre of gravity $= a$	4,548	4,634
It is assumed that the centre of gravity shall be before the middle of water-line $L = \frac{L}{80}$	2,055	1,919
Middle of water-line l abaft the middle of water-line L	0,375	0,375
Centre of gravity before the middle of water-line of $\overline{\text{construction } l} = \text{a}$	2,430	2,294
Situation of $\oplus$ section before centre of gravity $= \text{a} \,.\, \overline{n+1}$	7,957	7,478
Situation of $\oplus$ section before middle of water-line of construction $l = \text{a} \,.\, \overline{n+2}$	10,387	9,772

TABLE No. 42.—(*continued.*)

	36	32	28	24	20	16	14	12	10	8
h	10,144	9,3486	8,7545	8,3352	7,9478	7,0937	6,3669	5,6993	4,8653	4,1236
n	2,2447	2,2309	2,2199	2,2116	2,2037	2,1850	2,1675	2,1498	2,1250	2,1000
$\oplus$	386,89	337,67	302,73	278,90	257,59	213,17	178,08	148,07	113,75	86,35
d	13,872	12,909	12,184	11,669	11,190	10,125	9,2053	8,3500	7,2643	6,28
q	14,58	13,62	12,89	12,37	11,89	10,81	9,88	9,00	7,89	6,87
m	2,7209	2,6257	2,5528	2,5004	2,4514	2,3402	2,2431	2,1503	2,0280	1,9125
W	2244,8	1973,4	1760,1	1647,0	1527,7	1277,9	1078,9	906,83	707,92	546,8
r	4,7279	4,5512	4,4182	4,3228	4,2342	4,0350	3,8629	3,6973	3,4839	3,2841
$\int \frac{2}{3} y^3 \, dx$	456060	352180	290120	250640	217550	155460	113040	81471	51061	31351
p	12,183	11,572	11,255	11,016	10,790	10,283	9,8293	9,3807	8,7794	8,2000
s	1,5066	1,4834	1,4617	1,4505	1,4373	1,4050	1,3751	1,3446	1,3014	1,2563
g	5,0827	4,7145	4,4378	4,2412	4,0120	3,6547	3,3071	2,9850	2,5780	2,2109
e	7,100	6,858	6,817	6,775	6,778	6,628	6,522	6,396	6,201	5,989
v	2,134	1,991	1,884	1,807	1,736	1,577	1,440	1,311	1,147	0,997
a	4,966	4,867	4,933	4,968	5,042	5,051	5,082	5,085	5,054	4,992
$\frac{L}{80}$	1,783	1,666	1,578	1,515	1,457	1,327	1,218	1,109	0,974	0,852
Middle of, &c.	0,375	0,375	0,375	0,375	0,375	0,375	0,375	0,375	0,375	0,375
a.	2,158	2,041	1,953	1,890	1,832	1,702	1,593	1,484	1,349	1,227
a. $\overline{n+1}$	7,002	6,591	6,288	6,070	5,869	5,421	5,046	4,674	4,216	3,804
a. $\overline{n+2}$	9,160	8,631	8,241	7,960	7,701	7,123	6,639	6,158	5,565	5,031

TABLE No. 42.—(*continued.*)

	44	40
From middle of water-line L to ⊕ $= k$	10,01	9,40
Greater draught of water abaft than forward $= \frac{L^{0,653}}{15,744} = c$	1,78	1,70
Depths from the water-line L to the upper side of the keel forward and abaft. The sign + belongs to the after-depth, and the sign − to the foremost $= q \pm \overline{\frac{c}{2} \pm \frac{ck}{L}}$ abaft	17,81	16,65
forward	16,03	14,95
$\frac{l}{2}$	80,815	75,375
From the after-end of l to the ⊕ section =	91,202	85,147
Distance between the sections abaft, $\frac{1}{10}$ part of the above distance =	9,120	8,515
From the foremost end of l to the ⊕ section =	70,428	65,603
Distance between the sections forward, $\frac{1}{10}$ part of the above distance =	7,043	6,560
Height of battery above the water	8,67	8,33
Displacement to the outside of the planking $= \frac{20}{19} D = Q$	60813	49346
Moment of the ship's stability $= a\, Q$	276580	228670
Weight of the men at the guns and small-arms $= P$	626	513
Their centre of gravity from midships $= b$	14,0	13,4
Moment of these men in action $= b\, P$	8764	6874
(1) Moment of the power of the sails $= M$	25007	21045
(1) $59{,}56.\, M = W$	1489400	1253400
(1) From upper side of gun-deck to topmast fid $= B\, C$	5,50	5,13
(1) From centre of gravity to topmast fid $= d$	10,27	9,70
(1) Breadth of the lower edge of the maintopsail (2) $= x$	80,89	76,37

(1) See "the area of sails for ships of the line, § 12 and 13."

(2) The proportions of the sails of the fore and mizen-masts are the same as for those of ships of the line. The form of the stem being a conic parabola, &c. may be seen on the draughts.

TABLE No. 42.—(*continued.*)

	36	32	28	24	20	16	14	12	10	8
k	8,79	8,26	7,87	7,59	7,33	6,75	6,26	5,78	5,19	4,66
c	1,62	1,55	1,50	1,46	1,42	1,34	1,26	1,19	1,09	1,00
$q \pm \overline{\frac{c}{2} \pm \frac{c\,k}{L}}$ abaft	15,49	14,49	13,73	13,19	12,69	11,57	10,59	9,67	8,51	7,44
forward	13,87	12,94	12,23	11,73	11,27	10,23	9,33	8,49	7,43	6,44
$\frac{l}{2}$	69,93	65,265	61,755	59,235	56,895	51,690	47,185	42,97	37,595	32,600
From the after, &c.	79,090	73,896	69,996	67,195	64,596	58,813	53,824	49,128	43,160	37,631
Distance between, &c.	7,909	7,390	7,000	6,720	6,460	5,881	5,382	4,913	4,316	3,763
From the foremost, &c.	60,77	56,634	53,514	51,275	49,194	44,567	40,567	36,812	32,030	27,569
Distance between, &c.	6,077	5,663	5,351	5,128	4,919	4,457	4,057	3,681	3,203	2,757
Height of battery, &c.	7,75	7,25	7,00	6,67	6,33	5,83	5,33	5,00	4,50	4,00
Q	39404	32036	27135	23951	21171	15914	12105	9142	6122	4025
$a\,Q$	195680	155920	133860	118990	106744	80382	61517	46487	30940	20093
P	432	351	291	248	221	183	121	108	70	54
b	12,7	12,1	11,6	11,2	10,8	10,0	9,4	8,8	8,0	7,0
$b\,P$	5486	4247	3376	2778	2387	1830	1137	950	562	378
(1) M	18402	14787	12993	11744	10640	7980	6369	4524	3213	2074
(1) W	1096030	880710	773860	699470	633720	475290	379340	—	—	—
(1) $B\,C$	4,76	4,44	4,20	4,03	3,87	3,51	3,21	3,00	2,65	2,37
(1) d	8,97	8,35	7,99	7,56	7,13	6,54	6,00	5,58	5,00	4,37
(1) x	73,14	68,02	65,11	63,01	61,03	55,43	51,43	—	—	—

In case it is required that either of these vessels shall have a greater area of sails; then a, the distance between the centre of gravity and the metacentre is greater, and consequently the distance p is so much the greater; and put the new value $p = p'$. To find, therefore, the new breadth, a different expression from that in the table must be given for finding the moment of stability $\int \frac{2}{3} y^3 d x$, which is the same as for ships of the line, but adapted to frigates; namely, $\int \frac{2}{3} y^3 d x =$

$$\frac{\overline{\tfrac{1}{2} B^3 L}\big)^{1,04895}}{4,3325} = p' D, \text{ hence the new half breadth } \tfrac{1}{2} B' =$$

$$\sqrt[3]{\frac{4,3325\ p'\ D^{\frac{1}{1,04895}}}{L}}.$$

The situation of the centre of gravity appears thus to be much higher above the water-line in frigates than in ships of the line, which arises not only from the weight of the masts, yards, and rigging, being greater in relation to the displacement in frigates than in ships of the line, but also from frigates being sharper in the bottom.

As it is not necessary to be so particular as to the depth of smaller vessels; and as these vessels, on account of their light weight, possess little power to continue their way when they luff up to come to the wind; and as it is especially necessary that in coming about they should have as much way as possible, which takes place when the centre of gravity is in or near the middle of the length of the water-line of the vessel; and as both ends are equally full, a considerable difference of draught of water abaft must be given, by which the after-displacement is increased below, and is correspondingly decreased at the water-line, by which the stability is somewhat diminished, which can however be compensated by an increase of breadth in midships; which always determines itself in the construction of the drawings. The centre of effort of the sails should then come further aft, which also conduces to the vessel's readiness in coming about.

It is seen, as well from this Table as from Table No. 33, that although ships of the line, as well as frigates, are formed by rules founded on the same principle, they nevertheless vary

much in respect to their form.—Compare, for instance, the ⊕ section of the ship of 110 guns with that of the brig of 8 guns, and it will be found from their exponents that there is no similarity between them; when, therefore, the length, breadth, and depth of a ship are given, and the displacement within these limits, safe and constant rules can be formed, by which the drawings can be constructed.

A constant method of constructing the drawings is thus obtained, which is denominated the PARABOLIC METHOD OF CONSTRUCTION, (see § 40,) which is applicable to all sorts of ships and vessels, of every armament and for every purpose without exception; and will be found as indispensable to a person forming a ship's drawings, as logarithms are to a mathematician.

APPENDIX.

ON GUNS AND TRAVERSE CARRIAGES.

On Guns.

It may be inferred from what has been said, that a ship of war is to be regarded solely in relation to its guns; a description and general drawing of guns will be here given, such as they should be for the armament of ships, agreeably to the calibre measure adopted in Sweden.

Fig. 1. is a general drawing of all the guns commonly used in Sweden; namely, 48, 42, 36, 30, 24, 18, 12, 6, and 4-pounders: nine kinds. All of them are constructed by the same scale of calibre. The same principle on which this construction is founded was adopted by me some years ago, and is given in the new "Transactions of the Royal Academy of Sciences," vol. 23, for the year 1802; in the first quarter of which is inserted, *A Theoretical Treatise, founded on experiment, to give the proper form of guns, that their strength at all parts may be proportional to the expansive force of gunpowder, see Fig.* 3 *and* 5; and what was inserted in § 21 concerning the guns used at sea is to be observed.

b b is the bore of the gun, *b a a b* is the chamber for the powder, which is one-fifth smaller at the bottom *a a* than at the fore-part of the powder *b b*. The ticked line *d e f h k n*, which is the line of construction of the gun, is an hyperbola, within which line the external surface of the gun does not pass at any place before *e*.

If the gun were of a parallel bore to the bottom of the chamber, its external form at the after-part over the chamber would be *o d e*, if its strength were proportional to the expansive force of the powder; but as the gun would then be of an improper shape, and also of too great a weight, it has been found neces-

sary to diminish the width of the bore at the bottom of the chamber, as *a a*, and consequently its exterior diameter is diminished, so that it becomes *t u*, by which a considerable diminution is obtained in its weight, though it is nevertheless quite as strong as when the bore is parallel, and the exterior surface is *o d e*.

There is conclusive evidence that guns of this construction do not burst.

Between *f* and *g* the second reinforce moulding is terminated for all the nine sorts of guns, between *h* and *i* the first reinforce moulding is terminated, between *k* and *l* is the fore-part of the muzzle ring, and between *m* and *n* is the muzzle. The diameter of the gun at *e*, the foremost end of the powder chamber, is in a constant proportion to the calibre for all the guns. In other respects the manner of constructing the guns may be found from the drawing. All the measurements are made by the scale of calibre placed near it, and all the calibres, &c. are inserted in the following Table. The lower half of the figure represents a 36-pounder. Between *p* and *q* is the centre of the trunnion, and between *r* and *s* is the centre of gravity of each gun.

	48	42	36	30	24	18	12	6	4
Diameter of calibre, in feet	0,6586	0,6299	0,5984	0,5631	0,5228	0,475	0,4149	0,3292	0,2877
Length of bore, in feet	10,000	9,658	9,275	8,841	8,338	7,731	6,950	5,793	5,208
Length of bore, in calibres	15,2	15,333	15,5	15,7	15,949	16,276	16,751	17,597	18,102
Weight of gun, in skipponds light weight	30,986	27,230	23,454	19,660	15,840	11,990	8,097	4,139	2,795
Trunnion and trunnion plate in light weight	0,8	0,7	0,6	0,5	0,4	0,3	0,2	0,1	0,066
Total weight of gun, in skipponds lt. weight	31,786	27,930	24,054	20,160	16,240	12,290	8,297	4,239	2,861
Coins in lb. provision weight	33,86	29,95	26,56	23,04	19,36	15,52	11,26	6,56	4,67
From cascabel to centre of gravity, in calibres	7,825	7,864	7,913	7,971	8,043	8,141	8,276	8,520	8,665
Between centre of gravity and centre of trunnion, in calibres	0,574	0,581	0,603	0,630	0,665	0,717	0,788	0,937	1,038
Weight of shot in lb. provision weight	59,80	52,28	44,81	37,34	29,81	22,34	14,27	7,44	4,95
Number of shot = weight of gun	170	171	72	173	174	176	178	182	185
From centre of trunnion to muzzle, in feet	6,463	6,236	5,980	5,695	5,364	4,957	4,441	3,674	3,284
Length of trunnion beyond trunnion plate, in calibres	0,840	0,840	0,840	0,840	0,840	0,841	0,843	0,850	0,869
Length of gun from outer end of cascabel to muzzle, in feet	12,157	11,721	11,235	10,685	10,050	9,287	8,309	6,871	6,150
Weight of a charge of powder, in lb.	16,00	14,32	12,60	10,83	9,00	7,09	5,06	2,85	2,03

On the Traverse Carriage.

As the lower-deck guns, on account of their weight and their being more easily worked, should be placed on traverse carriages: an improved traverse carriage is drawn on the same plate, in which the sand and dirt cannot cause any impediment. See *Kännedom af Linie skepp*, note to § 4.

Fig. 2 is a 36-pounder, standing in board on its carriage, lying on the slide in the traverse. It can be elevated $8\frac{3}{4}$ degrees, and depressed $4\frac{1}{2}$, making together $13\frac{1}{4}$ degrees. At the midship port it can be trained forward $17\frac{1}{2}$ degrees, and as much abaft, making together 35 degrees.

A is the upper side of the traverse, *B* is the upper side of the slide, *C* its lower side, *D* is the upper side of the carriage, and *E* its lower side. *F* is the longitudinal section at the middle of the carriage, and *G* the longitudinal section of the slide. *H* is the transverse section through the pin of the slide *a*, the carriage *b*, the slide *c*, and the traverse *d*, and pillar *e*. *f* is the deck plank, *g* is the opening in the middle of the traverse in which the middle part of the slide *h* runs, which guides the gun in the recoil; in an iron secured to the slide *c* a paul catches against the stop *k*, when the gun recoils from the shot, that the gun may be brought to its place till it is loaded; but as the bolt with which the paul *i* is fastened to the slide cannot resist the concussion which the paul receives, when the breeching after the recoil draws the gun forward again, the iron, *θ* is fixed to the traverse close to the end of the paul to resist the concussion, and when it is loaded an iron bolt put into the hole *l* and the eye *m*, turns up the paul *i*, that the gun may run in board; and when the gun stands lashed within board, it is drawn so far in, that the paul *i* falls down into the stop *n*. In the hole *o* a bolt is put, between which and the end of the slide a wedge is driven in, by which the slide is secured between the paul and the bolt, so that it cannot come either in or out. *p* is a ring-bolt on each side of the traverse: through these rings a lashing is brought over the gun, by which it is so firmly secured to the deck that in the heaviest rolling it remains fixed and safe. From the lashing coming against the first and

second reinforce mouldings, the muzzle of the gun does not move at all at the ship's side. *q* is a cleat which confines the breeching. In the outer end of the traverse is a score for the breeching which keeps the remaining part of it in its place, by means of the small bolts *r*, through the iron eye plates *s*. On each side of the pillar *e* is an iron plate *t*, through which a bolt *v* passes during the explosion, to prevent the traverse from rising from the deck. By means of the hand-spike *w*, which fits into the mortise *x*, the traverse is turned about the pillar *e*, and gives the gun its lateral training.

When the gun is required to stand fore and aft at the ship's side, the elastic catch *y* is raised, and the carriage is turned round the pin of the slide *a*. *z* is an iron cleat to secure the catch *y*, by which the gun in being fired always stands in the same direction as the traverse.

When lying in harbour, and it is required to have a clear deck, the traverses can be turned round so far towards a fore and aft direction, that with 36-pounders they do not project from the ship's side more than 9 feet: the guns can also, if required, stand athwartships out of their respective ports.

When a ship is to be armed, and the guns are to be laid on the traverse carriages, they must be hoisted over the gunnel, and lowered down through the main-hatchway of the upper deck, on thick plank laid on the beams over the main-hatchway of the lower deck, on which the carriage with the slide is placed, in a small traverse fitted for the purpose, when the gun is lowered down into its carriage and carried in a truck with four small wheels to its traverse at the ship's side.

END.

1804.

A table of cubes from 0,25 to 28,99 is given in the original, which it is considered quite unnecessary to insert in this translation.

ADDITIONAL APPENDIX.

When I had finished this work, it suggested itself to me, whether the parabolic method of construction here given with its rules might be considered by many as not sufficiently general, being adapted only to such fuller or sharper ⊕ sections as are constructed according to this principle, that their greatest fulness shall be just below the water-line; but that it is not so, an example is here inserted, applicable to all kinds of ⊕ sections, of any form.

Form of a ⊕ section of a Frigate of 40 *Guns.*

The ⊕ section, Fig. 3, No. 1, is altered to the ⊕ section of the frigate of 40 guns, Fig. 4, No. 2, but containing the same area, same breadth at the water-line, and same depth as No. 1; also the displacement and length on the water-line the same, and with the same line of sections *h*; consequently, the areas of all the sections in No. 2 are equal to all the areas of the sections in No. 1, and the situation of the centre of gravity of the displacement in respect to length the same. They have the same sheer draught; the parts which are dissimilar are marked in No. 1 and No. 2; but although these two frigates are in all these particulars so much alike, and though No. 2 is $1\frac{1}{6}$ foot broader at $2\frac{3}{4}$ feet above the water-line, yet on account of the distance *b c*, Fig. 5, between the centres of gravity of the ships and their metacentres, the frigate No. 2 has its moment of stability one-sixth less than that of No. 1.

In the vertical line *E*, Fig. 5, the centres of gravity of displacement coincide at *a*, the centres of gravity of the ships and lading at *b*, and the metacentres at *c*, for both the frigates; the marks which are abaft this vertical line belong to the frigate No. 1, and those which are before it belong to the frigate No. 2; but the latter experiences somewhat less resistance in the water than the former, which may be found by the method given in this work.

Ordinates y	Ordinates of the section-line h	Half areas of the sections.	Ordinates of ribband-line, c.	
			Forward.	Abaft.
10	0,000	0,00	—	—
9	2,349	47,54	4,076	3,665
8	4,391	88,84	6,012	5,627
7	6,135	124,12	7,460	7,145
6	7,591	153,58	8,583	8,347
5	8,771	177,45	9,454	9,293
4	9,688	196,00	10,111	10,011
3	10,356	209,51	10,583	10,527
2	10,794	218,37	10,885	10,863
1	11,025	223,05	—	11,039
⊕	11,086	224,27	11,086	11,086

$$\text{Forward } C = 0{,}373 \,.\, h + 0{,}627 \sqrt{\mathbf{h}\, h}$$

$$\text{Abaft.. } C = 0{,}522 \,.\, h + 0{,}478 \sqrt{\mathbf{h}\, h}$$

Compare Table No. 40, page 3, for a frigate of 40 guns (which is No. 1) with the Table for the frigate No. 2; then it will be found that the difference is in the ordinates c of the ribband-line, which could not be inserted in Table No. 42, page 8, in which the general rules are found.

That the frigate No. 2 has one-sixth less stability than No. 1, arises from this cause: as both these frigates have their upper water-line of the same length and breadth in midships, and have the same area of ⊕ section, but No. 2 is fuller in the bottom; and as the displacement is to be equal in both, it follows, that as much as the displacement is increased in the bottom it will be diminished near the water-line, by which the load-water section is diminished from midships to both ends, and therefore $\int \frac{2}{3}\, y^3\, d\,x$ is less: and this is the reason that the load-water section W does not agree with the general rule in Table No. 42; but the following rules are applicable, when the area of the altered water-section is used.

It should however be observed, that the breadth of the ⊕ section of a ship or vessel is never so suddenly diminished immediately below the water-line as the frigate No. 2; consequently the area of the water-line cannot be so considerably diminished; but it has been taken in the extreme only to show, that the given method can be used for any form of ⊕ section;

likewise, in case it is required to have a vessel with the sides falling out as No. 2, and even more, and to have the area of the water-section as the frigate No. 1, the same method of construction may nevertheless be used.

As it is the fulness below which causes the diminution in the area of the water-section before and abaft the ⊕ section, this fulness below should be diminished, as shown by the ticked line *x x*, by which the half area of the ⊕ section is reduced by 3,156 square feet; and as the displacement is to remain constant, the same method is used which is inserted in Table No. 42;[1] whence $\mathbf{h} = 10{,}93$, the exponent of the line of sections $n = 2{,}37$, by which the form is changed. The situation of the ⊕ section comes thus further forward, because the situation of the centre of gravity is to remain the same, by which the stations, as well as the areas of all the other sections, are altered; and when the operation is performed in all respects as above-mentioned, nearly the same area and form at the water-line is obtained as in the frigate No. 1; but there is nevertheless a deficiency in the stability, for the reason assigned in § 22. It is remarked, that the addition, *f*, to the water-line of construction *l* can be increased or diminished, either forward or abaft, by which the length of the whole water-line *L* is greater or less. See the Tables No. 33 and 42. In the formation of the drawing the occasion of such an alteration may appear, but whether it be required in the largest or smallest vessel, this addition can never exceed three-fourths, or at most one foot.

It may hence be inferred, that this method of construction is suitable to every kind of ⊕ section. H. S. B.

As all the drawings in this work are made by the same scale, and all the lengths *L* of the upper water-line between the rabbets of the stem and sternpost are the same for those con-

1 By a little consideration of this Table a rule may be formed for any alteration which may be reasonably required. Also for ships of the line, from Table No. 33.

structed by the parabolic method, as for those whose form is founded on the direction of the line of relaxation, the scale has not been drawn on the sheer draughts of the parabolic sheer draughts.

What is common to all printed drawings occurs here, namely, the unequal shrinking of the paper; all the lengths on the sheer draughts ought however to agree with those on the same drawing by the scale, and all the breadths on the body plans ought to agree with the scale of that plan; but the breadths on the body plans do not always agree with the breadths on the sheer draughts; they can however be always corrected by a proportional triangle. The greatest difficulty is in the heights, which may not agree with either scale, and those on the body plans may not be equal to those on the sheer draughts; but they are known by the abscissas **k** and **h** of the line of sections in Tables No. 15 and 22, and No. 33 and 34 for ships of the line, and in Tables No. 34 and 35, and No. 39 and 40 for frigates, in which Tables are also found the lengths L and l and breadths B.

On this account, if this work should obtain circulation abroad, it is particularly necessary that the whole text be translated into the language of the country, otherwise the complete advantage of the plates cannot be obtained: also on account of this method of construction being entirely new; it is also necessary that the translator should not only understand the two languages, but should know mathematics, and be well acquainted with the common method of constructing the drawings of ships, and also the practical part of ship-building, &c. in order that he may properly understand what is here treated on, so as not to commit such errors as the French translator of my Treatise on Ship-building, printed at Stockholm in 1775, did, in which translation, printed in 1781, he pretends that he found a gross error in § 9; but in 1793, which is 12 years after, a work appears, in which he recants what he had said, and shows that he himself had made the mistake; how should such conduct be regarded?

Although (as was said in the Introduction, page 144, vol. 3) I am not certain that the long measures given there are cor-

rect; I have however (as the difference does not appear to be considerable, and in order not to be without any knowledge of them) drawn the scales of long measure of the following nations, in proportion to the Swedish scale, by which the drawings in this work are made; namely, Portugal, France, Denmark, Rhinland, England, Sweden, Dantzic, Holland, and Spain, or Cadiz. See Fig. 6.

On the security of Ships' Decks without the use of Wooden Knees.

Great difficulty is experienced from the remarkable diminution in timber, in obtaining a sufficient number of oak timbers and oak plank of such size and length as to form a good combination; on the same account it is difficult to obtain a sufficient number of suitable oak knees, especially those which are large; and what constitutes in the greatest degree this difficulty is, that it is at this time very rare to obtain oaks, whose branches spread more than 45 degrees from the upright trunk of the tree, whereas they should at least form an angle of 60 degrees, and from that to 80 degrees, which latter kind is exceedingly rare; this want of oak knees has been supplied by the use of *knees of spruce fir*, which have been used in this manner; the trunk of the tree has been used as the principal arm of the knee, and its root as the branch or small arm of the knee.

All the firs which grow on level ground have their roots always perpendicular to the trunk, and are thus fit for lodging knees; but the roots of those firs which grow on sloping ground form greater or less angles with the trunk than right angles, according as the ground is more or less inclined; that is, the one grows up the sloping ground and the other down it, and it is the latter which are used as hanging knees. These roots have always sufficient thickness for the sidings, but the oak roots are always too thin in this respect. The roots of the fir are tougher than those of the oak, but are more liable to be rotten, and especially the trunk, on which account the fir knees cannot be used as lodging knees, in consequence of the expense which would be incurred in shifting them and putting

new knees in their place; but this change can be accomplished without difficulty or inconvenience with the hanging knees.

In consideration of all these circumstances it is now more than twenty years since the decks of our ships of the line and frigates have been secured only with an iron hook, and a large bolt through the ship's side, instead of the lodging knee, and with a hanging knee of fir properly bolted; but this expedient also seems not to be able to be continued long, because it is easier to obtain 20 lodging knees than one hanging knee of the fir root: and it is on account of this very important reason that I have been led to consider, in what manner the decks of ships could be secured to the sides without the use of wooden knees.

As the want of iron can never be experienced, this is the only material with which the decks of ships should henceforth be secured to the sides; but in what manner it can be used to answer the purpose is the question which here offers itself for consideration.

The object is first, to secure the ends of the beams of the decks to the ship's sides, so that they cannot separate from them.

Secondly, with the sudden rolling which a ship experiences from one side to the other, that the vertical angle which the beams make with the ship's sides, may not be considerably altered. And thirdly, that if by the means adopted for this purpose any part may require repair, it may be conveniently done; and that this method may not in any way retard the working of the guns.

To obtain this object, the following method is proposed: see Fig. 7 and 8. Fig. 7 shows the side of a ship of 74 guns from the gunwale to the water's edge. Fig. 8 shows a transverse section of the ship's side, also from the gunwale to the water's edge. *A* is a lower-deck beam, *A* 1 the upper side of the beam; *B* an upper-deck beam; and *C* a quarter-deck or forecastle beam. The scale *F* gives the dimensions only of the wood work. The iron work with which the beams are secured to the ship's side is marked with a [1] blue tint, and is called the

[1] It has not been considered necessary to colour the iron work in the figures of this translation.

hooks; those which secure the ends of the beams to the ship's sides are called *horizontal hooks*, as *E e;* and those which during the ship's rolling prevent the alteration of the vertical angle of the beam with the ship's side from being considerable, are called *vertical hooks*, as *D d.* The part of these hooks which is fastened to the side of the beams and extends to the ship's side, is called in the horizontal hooks the *arm*, and in the vertical hooks the *leg;* the part of these hooks which is fastened to the ship's side is called in the horizontal hooks the *toe*, and in the vertical hooks the *lip*. As it must be supposed that the dimensions of the beams of the decks have been given a proper proportion to the weight they have to sustain, and to the force which acts on them, it follows that the iron hooks should be in proportion to the beams; and as all the beams, as well the larger as the smaller, may be regarded as nearly similar, and the thickness up and down is the dimension which has the greatest effect on the strength of the beams, this moulded thickness of the beams in the middle has been divided into 13 equal parts, which I have called the module, and each module is divided into 8 parts; see Fig. 7, the beams *A, B, C.*

By this small modular scale all the iron hooks in Fig. 7 and 8 are drawn; but as their dimensions cannot be clearly shown in these small figures, a larger modular scale *G* is made, by which the vertical hooks *D* and the horizontal hooks *E* are drawn. *h* is the side of the leg of the vertical hook, which is turned to the beam; *x* is the tenon which is let wholly into the beam, in which is a hole for the bolt *n* which passes through the beam, and is fastened on the other side of the beam with a ring and forelock; *g* is the outside of this leg; *k* is the side of the hook which is turned towards midships, at the upper end of which is the tenon, and at the lower end the blade *t*, in which is a hole for the bolt *l* which is driven through it, and is clinched on a plate without board, which is three times the diameter of the bolt in breadth, and in thickness half the module; *q* is the side of the arm of the horizontal hook *E*, which lies against the beam, and its tenon *x* is let wholly into the side of the beam; through the hole in it passes the bolt *v*, which is fore-locked on the other side of the beam, *p* is the outside of this arm, *r* is the side of the toe which is turned towards the middle

of the ship, the hole is for the bolt *o* to pass through, which is clinched without board, in the same manner as the bolt *l*; *s* shows the upper side of the hook together with its tenon *x*. The bevelling which the toe should have with the arm is determined by the greater or less tumbling home of the ship's side.

The small marks *o*, at the extremities of these iron hooks, show the holes for nails, with which they are fastened while the bolt holes are being bored through the ship's side and the beams. The numbers on these figures show their dimensions in modules.

Each end of the beams of these three decks is secured to the ship's side with two horizontal and one vertical hook; but every beam of the lower deck has an additional vertical hook.

All the beams of the orlop-deck have a horizontal hook at each end, and the beams which are between the mizen and foremasts have two: all the bolts in the hooks of this deck are driven from without board.

These hooks must be made of good tough iron, and the tenon *x* should not be welded to the arm or leg, but be wrought in one piece, because the whole strength of this fastening depends almost entirely on the tenons *x* and the bolts which pass through the ship's side. The bolt-holes in both ends of these hooks should be drilled.

The quickwork between the ports is commonly of thin fir plank; but the plank through which the bolts of the vertical hooks pass must be of oak. It should also be observed, that however important it is that the ends of the beams should fit close to the timbers, this should be the case only at the middle of the depth of the beam; but not at the upper or lower part, because the beams must necessarily be allowed a little angular motion in a vertical direction with the timbers.

It is found that neither the weight nor the expense of this method is greater than that of oak knees, and it is incomparably more durable.

I have now given the proportion and form of the iron work, with which the beams should be secured to the ship's sides; but whether it is sufficiently strong can be known only by comparison with other iron work, which withstands the same violent rolling of the ship, such as the chains, which after

many years' experience have obtained the size at present used.

The bolts which pass through the blades of the vertical hooks should be proportioned to the chain bolts, because the direction of the force they have to resist is nearly the same, and as these bolts are given the same strength as the main chain bolts together with the preventer bolts, and the leg of the hook is of considerably greater strength than a link of the chains of the same mast; and as the number of these hooks is much greater than the number of chains for the three masts, and when is added to these the fastening of the beams of the upper deck, and of the quarter-deck and forecastle, which are also secured with vertical hooks, there can be no mistake in considering the security of the decks in respect to the transverse rolling of the ship as sufficient.

When the moment of the rolling of the weights is considered, which is as these weights multiplied by the square of their distances from the centre of gravity of the ship, which must be estimated in every direction, above, below, and at the sides of this centre; this relation of the moment of the rolling of the weights of the masts, &c. with the strength of the chains, is not unreasonably compared with the moment of all the weights in the ship in relation to the strength of all the hooks of the decks together.

The strength of this iron work which secures the ends of the beams close to the ship's sides, is known from experience to fully answer the object; and in case any ship has its centre of gravity below the water-line, whereby it receives sudden strains during the rolling, or when a ship loses its masts, and thereby has not the means of easing the rolling, on such account it is necessary to strengthen the decks with proper standards of the roots of fir, or of iron.

In case the beams are placed differently from those shown in the drawing, for example, one over each port, and one between every two ports, then the beam which is over the port can have only the two horizontal hooks, and that between the ports has two horizontal and two vertical hooks; in which case there is the same number of horizontal and vertical hooks as in the former disposition. This is the manner in which the beams of

the decks should be secured to the ship's sides, by which the object mentioned above, in all the three conditions, is obtained: and it plainly appears that this method of security does not cause any hinderance in the working of the guns.

The use of iron instead of wood in securing the beams to a ship's side, is not new: such has been for a long time the practice in France, but not in this manner.

To the note at page 281, vol. 3, must be added the following, namely (see Fig. 79), the resistance in this case forward is $= G\,D\,E\,C$, and the effect of the water abaft is $= G\,B\,F\,C$.

In what manner the Arching of a Ship may in a considerable degree be prevented.

When the form of a ship in the water, and its upper works, with the situation of the weights by which it is pressed down are considered, it is found that the volumes of water at the extremities of the ship do not in any manner counterbalance the weights which they have to sustain: consequently, if a ship were cut transversely into numerous parts, and each part were enclosed at its ends, so as to be water-tight, those parts nearest the extremities of the ship would sink much deeper, and the middle parts would rise higher out of the water, and would thus assume a different form from that shown in the drawing, namely, higher in midships and lower at the extremities. And as the form of a ship above or below the water cannot be otherwise than it is now and always has been, nor can the situation of the weights by which the ship is pressed down, be altered, this defect can be obviated in no other manner than by a certain security through the whole length of the ship, not, however, wholly, but in a greater or less degree, depending on using the best means, and those which cause the least inconvenience. I will mention what has been done in this respect.

In the year 1759 two vessels were built at Stralsund, on the King's account, to be used in the Frische-haf in a war with the King of Prussia, the one about 100 feet long, and above 20 feet

n breadth, and drawing not more water than $7\frac{1}{2}$ feet: the other about 80 feet in length, and drawing $5\frac{1}{2}$ feet water; they carried heavy armaments, especially at the extremities; and were made to row as well as sail: and on account of this armament and the many considerable weights, a strong combination of the fabric was necessary; but although their bottoms had the greatest fulness which could be reasonably allowed to them, they could not thereby obtain a sufficient displacement. It was therefore necessary to build them with timbers of as small scantling as possible; and as on this account they could not possess the necessary strength, especially in regard to their arching; in order to avoid this defect, the following method of security was considered best for them.

Parallel to the middle line of the vessels on each side, about half way between the keelson and the orlop clamps, a strake of oak was laid on its edge six inches thick, along the whole length of the hold, let down an inch over all the timbers, the ends of which extended to the deck, both forward and abaft, which was called the builge-strake, and which was fastened with bolts through the timbers and outside plank. Under the beams of the deck, perpendicularly over the builge-strake, was fixed on its edge a strake of fir along the whole length of the vessel six inches thick, with a score one inch deep for the beams, to which it was bolted, and was called the longitudinal shelf. Both ends of this shelf lay against the timbers of the frame, and its lower side on the builge-strake, to which it was coaked, both forward and abaft, and was fastened with bolts through the builge-strake, timbers, and outside plank. Between the builge-strake and the shelf vertical oak pillars were placed, at a distance from each other equal to their length; from the lower end of one pillar to the upper end of following pillar was placed a diagonal shore of fir. See more on this subject in the *Architectura Navalis Mercatoria*, printed at Stockholm in the year 1768, Plate 36, Fig. 5, and in the treatise on ship-building relating to it, printed at Stockholm in the year 1775, page 217: and as it was found that the object was obtained by the use of this diagonal trussing, which was adopted for the first time in this instance, all armed vessels, as well great as small, have been given a trussing in all respects similar to it.

For further proof of the effect of this method of preventing arching the following is inserted :—

In the year 1772 an armed vessel was built at Stockholm about the same size as that first named, but instead of the vertical pillars being of oak as in the former vessel, they were of fir in this vessel, but in all other respects as before. Immediately it was come off the slip it was found that it had straightened in the launching four inches, but within twenty-four hours after, it recovered so much of its former sheer, that the sheer was straightened by only two inches. When it was examined in what manner it had taken place, it was found that the abutments of the shelf had pressed into the vertical fir pillars, nearly half an inch in some of them, and it was this yielding of the timber, which in some degree recovered itself, by which the arching was diminished ; on the lower ends of the pillars against the wedges little or no indentation was observed. It should likewise be remarked, that the sliding plank on which the builge-ways ran, during the launching, did not extend to the edge of the water, but terminated about a foot above it, by which, when the middle of the vessel was at the end of the sliding plank, its foremost end had not the support of the water which was required, and became balanced ; and it was just at this moment that the arching must have taken place.

Again.—About the year 1789 two larger vessels were built, each carrying one tier of 36-pounders ; how it happened, that they had not the usual diagonal trussing, I do not know : they were used in the Russian war, and were much arched, and when in too short a period afterwards they received a large repair, it was found that the keel, which was 135 feet in length, had curved upwards in midships $2\frac{1}{4}$ feet, on which account the usual diagonal trussing in the hold was given to them.

In consequence of so much evidence on the effect of this method of security in preventing a ship's arching, there is every reason to believe, that it will also produce the same effect on ships of the line, which become sometimes in a short time considerably arched.

Suppose it is required to make a similar disposition of security for a ship of the line, for instance, the ship of 110 guns given in this Treatise, and let Fig. 9 and 10 represent this arrangement.

As this strengthening should be applied at that place which is found most convenient in respect to the stowage of the hold, which it is most important to consider, and this is, to obtain a sufficient breadth for a certain number of water-casks, which is here considered to be four whole and one half cask on each side the keelson on midship pillars; if five whole casks were taken, the trussing would come too far out into the builge; besides, the nearer it comes to the middle of the ship the greater effect it has in preventing arching; therefore, when the diameters of four whole and one half cask are added together, with half the thickness of the midship pillar, and the whole thickness of the diagonal shores, it gives $18\frac{2}{3}$ feet, which is the distance of the middle line of the ship from the outside of the diagonal shores. To show this trussing, the ship's side, from one end to the other, as far as this trussing extends, is supposed to be laid open. *a*, is the frame timbers, *b* the ceiling, *c* the riders, *d* the builge-strake; *e* the fillings between the riders, builge-strake, and ceiling; *f* the shelf under the beams, which is in two thicknesses in breadth, which are bolted together to give shift to each other. Over these are laid three strakes of deck plank of such a thickness that they can be let down one inch over the beams, with bolts through these beams and the shelf. *g* is the vertical pillar, and *h* the diagonal or shore. In other respects the disposition of the pillars and trusses, &c. is as already described.

It must be farther remarked, that all the parts which belong to this trussing, and terminate at the extremities of the ship, are there secured in the best manner to the ship: therefore not only must the ends of the builge-strake and shelf be coaked together at the extremities of the ship, but also the security there required is supplied by fillings lying longitudinally, which are not only coaked together, but also to the builge-strake and shelf; and which extend as far as where the shelf and builge-strake are about 2 or $2\frac{1}{2}$ feet apart, by which the whole mass, namely, the shelf, filling, builge-strake, timbers, and outer plank, receive a sufficient number of bolts, which are driven from without and within, as *x x*. Likewise the fillings *e* under the builge-strake and between the riders are coaked to the ceiling, and the builge-strake to the fillings *e*; the combination of this disposition of trussing at both extremities of the ship cannot always be performed in the same man-

ner; for example, if the trussing comes nearer to, or farther from, the middle line of the ship, or if the ship has greater or less fulness at the extremities, &c., each of these cases requires a different method, the circumstance of the part to be strengthened will determine the manner of performing it.

This method of security, when it is done strongly and is well executed, will certainly accomplish the object. That the effect in preventing arching is of consequence may be inferred hence: that when a coasting vessel, which was to carry a considerable armament, and which was more than 100 feet long, strengthened in this manner, was to be launched, and the day before going off, the wedges at the lower ends of the pillars were for the last time driven up, it occurred: that when all the wedges at the pillars fore and aft on both sides were hardened up at the same time, it produced this effect, that the upper end of the keel rose so much from the upper block, that the block became loosened and moveable. It should also be remarked, that this vessel was not deep in the hold, had only one deck, with light upper works and small scantlings.

As the quantity of all this timber and iron work required for this trussing would be equal to the weight of 1200 cubic feet of water, the three-decker would sink about $1\frac{1}{2}$ inch deeper in the water, by which the height of the battery would be so much the less; but as this should not be allowed, the drawing should be altered, so that the displacement, which is = 152875, may become = 154075 cubic feet; and the alteration can be made in this manner, namely—

To keep the ⊕ section and all the other sections at the same places as before, the exponent n of the line of sections remains the same, = 2,6385, whence the area of the ⊕ section is $= \frac{n + 1 \,.\, D}{n \; l} = 1027{,}20$ (see the rules in Table No. 33, page 360, vol. 3, and the note page 23, vol. 4, for frigates of 40 guns). Let **h** be a tenth of an inch longer, then **h** is = 18,213, hence B is = 56,4; the breadth has thus obtained an increase of 0,13 foot.

The lowering of the metacentre, which is caused by the increase of the displacement, is counterbalanced by the small increase of the breadth; thus the situation of the metacentre is not changed. Perform the operations as for the ship of

110 guns, page 366, vol. 3, Table No. 34, then all the ordinates h of the line of sections will be obtained, and thence the areas of the sections and the ordinates c of the ribband-line.

From the two examples which are given at the beginning and end of this additional Appendix, it may be seen of what advantage the parabolic method of construction is, especially in the accuracy and ease with which very many alterations in the different elements can be made, to obtain the object and qualities required; and this is the additional evidence which was spoken of at the conclusion of § 53.

The following observation will be here inserted, which ought to have been in a note to § 42, page 358, vol. 3; in lines 23 and 24 it stands—"*that their common centre of gravity may coincide in T?*" The note ought to be this, namely: As all nations do not fit their ships in the same manner, by which the common centre of gravity of all the weights neither is, nor can be, at the same place longitudinally; and as it also happens, that vessels are built for certain purposes which require some particular fitting, by which the situation of certain weights is fixed, and for which there is scarcely room, it is therefore particularly necessary, that, after the magnitude of the vessel has been found as correctly as possible, a copy of the draught should be made, in which all the weights and ballast should be placed in their proper situations in the vessel, by which the common centre of gravity of the displacement may come to its proper place longitudinally, otherwise it would be necessary to place the ballast where it should not be, in order to give to the vessel its determined trim.

In conclusion: as the method of the construction of ships which I have given above, which is equally applicable to particular as well as general cases, is the fruit of many years' research, without being grounded on other authors; and as this work must inevitably, at my great age, be the last effort of my various endeavours to perfect the science of ship-building, I may be allowed to dedicate it as my *testament* or memorial of what I have been able to contribute to it, to all enlightened admirers of this noble science.

1806.

ART. II.—*On Rotatory and Rectilinear Motions; with Observations on the Effects of those Forces which are, in some cases, brought into operation by them.* By Mr. LLOYD, of H. M Dock Yard, Portsmouth, formerly of the School of Naval Architecture.

IT is well known that the rotatory motion of a body, in free space, always takes place round an axis passing through its centre of gravity. It is true, also, when bodies are immersed in fluids, and acted on by variable forces. This fact, however, has been frequently denied, by men too, possessing considerable knowledge of subjects connected with naval science.

Mr. Wilson, of the Navy Office, in his "Observations on a Ship's Rolling," No. 9, page 81 of this work, after having stated that some writers consider that a ship in rolling turns round an axis passing through the centre of gravity, says, "On the contrary, other writers, and Chapman among them, whose name alone is a host on subjects of naval science, consider the axis of rotation to pass through the metacentre."

Every person who has the pleasure of knowing Mr. Wilson must be well aware that the solidity of his judgment, arising from the cautious, philosophic manner in which he avails himself of his vast information, causes the greatest respect to be paid to his opinions: for this reason, it is the more desirable to examine the correctness of what he has advanced.

In the above quotation, Chapman is said to have sanctioned the opinion, that a ship in rolling does not revolve round an axis passing through the centre of gravity; it is generally difficult to prove a negative fact, but in this case it almost amounts to the same thing, if it can be proved that he asserts the contrary of what is here ascribed to him; for he is not likely to be inconsistent with himself, and even if he should be, his authority on this point would be neutralized.

In Chap. 3 of his "Treatise on Ship Building," translated by Professor Inman, in treating on the rolling of ships, and on the method for finding the length of the isochronal pendulum, he says, page 26, "it is sufficiently clear that the metacentre g or G may be considered as the centre of percussion." He could not, therefore, consider that the ship revolved round an

axis passing through that point. But he expressly says, in several places, that the point through which the axis passes is the centre of gravity. Thus, page 24, "But the ship during the inclination is supposed to revolve round its centre of gravity." Also, page 26, "The angular motion of a ship round its centre of gravity being stopped . . . . but as the vessel, without farther opposition, is supposed to roll back round its centre of gravity . . . . . ." From these passages, and others of a like tendency, it is inferred that Chapman cannot be considered as having entertained the opinion ascribed to him.

Perhaps the clearest manner of showing that the axis of rotation must pass through the centre of gravity, and of explaining, in some particular instances, the effect of forces acting on a ship, will be first to inquire into the motions of a body in free space, acted on by any number of constant forces. For, the truth of the conclusions arrived at in this case being capable of strict demonstration, they may be taken as premises, from which it will be easy to draw other conclusions applicable to the motions of a ship.

It is unnecessary to prove, that if any number of forces act on a body, the pressure on the centre of gravity, and therefore its motion, will be the same as if they were all collected at that point. It is also well known that any force, the direction of which does not pass through the centre of gravity, will have a tendency to turn the body round an axis passing through it: which axis is perpendicular to the plane passing through the line representing the force and the centre of gravity.

As these two motions are totally independent of each other, they may be considered separately: that is to say, the rectilinear motion of the centre of gravity as if no rotatory existed, and the rotatory motion as if the centre of gravity were fixed.

Let three planes be supposed to pass through the centre of gravity, so that every one may be perpendicular to the other two: it is evident that the three lines formed by the intersections of the planes will likewise be perpendicular to one another. All forces not acting in directions parallel to these lines, can be resolved into others which are in those directions. This is immediately seen by conceiving those lines representing the

forces, which, if produced, would cut the *three* planes, as diagonals of rectangular parallelopipeds, made up of planes parallel to those passing through the centre of gravity; and those which would cut *two* of the planes only, as hypothenuses of right angled triangles, whose sides are parallel to those two planes, and the planes of the triangles parallel to the third one.

Having resolved the whole of the forces into others, parallel to the lines formed by the intersections of the planes passing through the centre of gravity, let the sum of the resolved forces acting in the same direction be taken. Now, suppose a rectangular parallelopiped to be so constructed, that three of its planes shall coincide with the three planes passing through the centre of gravity, and its length, breadth, and height, be equal to the sum of the resolved forces in those directions respectively; then its diagonal, drawn from the centre of gravity, will represent a force which, acting at that point, would, in the same time, generate the same rectilinear motion as would be generated by the combined action of the original forces.

It is not necessary, however, to have recourse to construction to determine the length or direction of this diagonal, as it is at once seen that the length is equal to the square root of the sum of the squares of the three dimensions of the parallelopiped; and its direction is known, as the cosine of the angle it makes with any line formed by the intersections of the planes of the parallelopiped, is equal to that line divided by the diagonal.

In order to determine the effect of the forces in producing rotatory motion, the centre of gravity is supposed to be fixed.

The effect of a single force in producing rotatory motion, is in proportion to the force multiplied by the line joining the centre of gravity and the point at which the force acts, multiplied by the sine of the angle made by this line and the one in the direction of the force. If the whole of the forces acted in one of the three planes passing through the centre of gravity, they would turn the body about an axis formed by the intersection of the other two; and their joint effect would be found by taking the effects of the forces separately, and adding them together.

As the axis round which any force tends to turn the body,

is perpendicular to the plane passing through the line of the force and the centre of gravity, it is evident that the application of any force which does not act in the plane in which the other forces act, causes the body to turn round an axis inclined to the former one. Let us, therefore, inquire how the direction of the axis may be determined, round which the body revolves, by the combined action of forces which are neither in the same plane nor in parallel directions.

All the forces being resolved into others perpendicular to the three planes passing through the centre of gravity, let the effect of the resolved forces in turning the body round the axis, coinciding with the intersections of these planes, be determined separately. This is done by drawing lines from the points at which they act perpendicular to the axis, round which their effect in producing rotatory motion is to be calculated; and by taking the sum of the products obtained by multiplying each resolved force by its corresponding line thus drawn, and by the sine of the angle contained by this line and that of the resolved force. Or, which amounts to the same thing, by taking the sum of the resolved forces multiplied by their respective perpendicular distances from the plane to which they are parallel, and in which the axis lies.

Two of the axes are, of course, supposed to be free, while the effect of the forces in causing rotatory motion round the third one is being determined.

Now, it is evident that if the relative distance of a force from the three axes be the same, its direction remaining unaltered, the same rotatory motion will be produced if the force vary inversely as its distance from them. Let a line, then, be drawn in the plane of two of the axes, and parallel to one of them, at any distance from it, by which distance divide the measure of the effect of the resolved forces in producing motion round this axis. A force equal to the result will, if applied at any part of the line thus drawn perpendicular to the plane passing through it and the centre of gravity, have the same effect in turning the body round *this* axis as the resolved forces.

Let this force be supposed to move parallel to itself along this line, until the force multiplied by its perpendicular distance from the other axis, becomes equal to the measure of the effect

of the resolved forces round it. This force, then, will have the same tendency to produce motion round the *two* axes as the resolved forces.

At the point at which this force acts, and perpendicular to it, let a second force be applied in any direction, not passing through the centre of gravity, so that its efficacy in producing motion round the third axis may be equal to that of the resolved forces. The diagonal of the lines representing these two forces will represent one, which alone will generate the same rotatory motion as the original forces, and round the same axis. This axis is, as was before stated, perpendicular to the plane passing through the centre of gravity and the line of the force.

Let a line equal and parallel to this one be drawn from the centre of gravity.

We have already found a line representing a force at the centre of gravity, the effect of which in producing rectilinear motion is equal to that of the original forces. The line, therefore, joining the extremity of these two will represent the force at the centre of gravity, which acting in conjunction with that producing rotatory motion, will produce the same effect as the combined action of the whole of the original forces.

It has been said that the force producing motion round the third axis may be applied in any direction; the quantity and direction of the force to be applied at the centre of gravity are alone affected: for it will be seen, by a little consideration, that the plane passing through the resultant and the centre of gravity will always remain the same; as also will the resultant multiplied by its perpendicular distance from the centre of gravity.[1]

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[1] It may be thus demonstrated:—Let *c* Fig. 11 be the centre of gravity of the body, through which the axis passes perpendicular to the plane of the paper, and *a* the point at which the force acts in the same direction: at the point *a*, also, the other force is to be applied in any direction in the plane of the paper. The resultant of these two forces is always in the same plane.

Let af, af_1 represent two forces, which have the same effect in turning the body round the axis passing through *c*. Let af be perpendicular to ac.

As we know the situation and direction of a force which will produce the same rotatory motion as the whole of the original forces, the point may easily be found, at which, if any given force were applied, the same effect would be produced. It immediately follows from this, that if the motion of the centre of gravity be perpendicular to the axis round which the body revolves, it becomes unnecessary to apply a force at the centre of gravity, as the situation of the one producing rotatory motion can be determined, so that its quantity and direction shall be such that it will generate the necessary rectilinear motion.

We see, therefore, that two forces, and sometimes one, can be found, which will produce the same effect as any number of constant forces acting in various directions.

It will, no doubt, be at once admitted, that the same effect which is produced by the action of fluids on a body may be produced by the action of an indefinite number of variable forces acting at different points. If so, it immediately follows, from what has been shown, that if at any particular instant the forces be supposed constant, one force may be so applied as to have the same effect in producing rotatory motion as the combined action of the whole of them; and if this force should not

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Draw $c\,b$ perpendicular to $a f_{\prime}$, and join $f f_{\prime}$.

$$\text{Now, } a c \times a f = a f_{\prime} \times c b$$

$\therefore\ a c : c b = a f_{\prime} : a f$, and the angles $f a f_{\prime}$, $a c b$, being equal, the triangles $f a f_{\prime}$, $b c a$, are similar. $a f f_{\prime}$ is therefore a right angle. Hence $a c$ is parallel to $f f_{\prime}$.

At f and $f_{\prime}$ let lines be drawn parallel and equal to the line representing the force at a, which is perpendicular to the plane of the paper. The lines joining the point a and the upper extremities of these lines will represent the resultants. It is evident that these resultants and $a c$ are in the same plane, since $a c$ and the line joining the extremities of the resultants are each of them parallel to $f f$.

It is also evident, from similar triangles, that the resultant, of which $a f$ is the vertical projection, $\times\ a c =$ the resultant of which $a f_{\prime}$ is a similar projection, $\times$ the perpendicular drawn to it from the point c. The effect, therefore, of the resultant in producing rotatory motion round the vertical axis passing through c, is the same whatever be the direction of $a f_{\prime}$.

produce the same motion of the centre of gravity, it may be produced by applying at that point a second force to act in conjunction with the first. At the next instant, other two forces may be so applied as to produce the same effects as the variable forces, and so on for every successive instant of time. It is evident, then, that by the action of two forces the quantity and direction of which are continually varying, the same effects may be produced as by the action of fluids, either in combination or not, with the action of any other forces whatever.

The only question now is, What effects will be produced by these two variable forces? It is quite certain that the one at the centre of gravity can neither accelerate nor retard the rotatory motion, nor can it alter the position of the axis round which it takes place. The rotatory motion will, therefore, be the same, in every respect, as if the body were acted on by one force only.

If the quantity and direction of this force be supposed constant during successive increments of time, the axis round which it will tend to turn the body during each of them will pass through the centre of gravity; that is to say, the centre of gravity will have no rotatory motion communicated to it. This is true, however small those increments are taken; it is, therefore, true when they are evanescent, or, in other words, when the force is constantly varying.

It may, perhaps, be unnecessary to remark, that the centre of gravity cannot remain at rest, unless the resultant of all the forces supposed to be collected at that point becomes equal to nothing.

Although the motion of the centre of gravity and the rotatory motion do not affect each other, yet, in some cases, forces which are consequent upon them being brought into action, produce effects on both these motions.

In order to illustrate this observation, we will take two or three instances in which the said forces have been overlooked.

Mr. Major, in the "Annals of Philosophy," No. 66, page 411, proposes the following method for finding the height of the centre of gravity of a ship:—

An horizontal lateral force is applied at some part of the mast or topmast, and the angle of the ship's inclination noted.

The ship is then allowed to resume her upright position, and by means of a greater force, applied in the same manner as the first one, but at a less height, she is inclined to the same angle as before.

The effect of each force, in inclining the ship, is as the force multiplied by the line drawn from the point at which it acts at right angles to the longitudinal horizontal axis passing through the centre of gravity, multiplied by the cosine of the ship's angle of inclination. The angle of inclination being the same in both cases, it is inferred that the first force × the line drawn from the point at which it acts perpendicular to the axis × cos. of the angle of inclination = the second force × the line drawn from the point at which it acts perpendicular to the axis × cos. of the angle of inclination. The cos. of the angle of inclination may be struck out, as it is found in both sides of the equation. The distance of the two forces from each other, as well as the forces themselves, being known, the distance of the axis from either of them may be calculated.

Now, those inclining forces which are brought into operation by the lateral motion are not taken into account. Let us inquire what effect these forces will produce.

It is very evident that the lateral motion will continue to increase until the horizontal lateral force, arising from the resistance of the water, becomes equal to the horizontal force which produces the motion. These two forces must be in the same vertical plane, since there is no motion round a vertical axis. To this plane the vertical force arising from the resistance of the water may be transferred, its distance from the longitudinal axis remaining the same; for it is not necessary to estimate its effect in producing motion round a transverse horizontal axis.

The lateral and vertical forces of the water either assist in inclining the ship, or the contrary, according as the lines in their direction, when produced, pass below or above the longitudinal axis passing through the centre of gravity. We have no means of ascertaining the absolute effect of these forces, as we know neither the height of the longitudinal axis nor the amount of the vertical force, nor the points at which the two

forces act. We may, nevertheless, see in what manner they affect the result of the experiment.

Let the resultant of these two forces be produced until it intersects the longitudinal plane passing through the middle of the ship. The forces may be supposed to be transferred to the point of intersection, the horizontal force being equal to the one applied to produce inclination, and the vertical force unknown. The effect of the vertical force is as the force × the distance of the point at which it acts from the axis × sine of the angle of the ship's inclination. If the angle of inclination be small, the effect of this force is inconsiderable when compared with that of the horizontal one; we will therefore, for a moment, disregard it.[1]

The effect of the horizontal force is as the force × the distance of the point at which it acts from the axis × cos. of the ship's inclination. According as this force passes above or below the axis of rotation, this expression for its effect must be subtracted from, or added to that for the effect of the horizontal force applied at the mast. In this case, therefore, the result of the experiment would be an approximation to the height of that point in the vertical longitudinal section, through which the line of mean resistance passes.

If the vertical resistance be too great to be neglected, the point found would be something above or below the one just mentioned, according as this point is above or below the axis passing through the centre of gravity; thus removing the point still farther from this axis.

If the inclining forces were applied perpendicular to the plane of the masts, then, whatever be the inclination of the ship, the point determined would be the one in the vertical longitudinal plane through which the resultant of the water passes. For, in this case, the resultant may be resolved into

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1 It must be remembered, that when the effect of the vertical force is spoken of as being small in comparison with that of the horizontal one, it is after those forces are transferred to the point where their resultant cuts the longitudinal plane passing through the middle of the ship.

two forces, one perpendicular to the inclining force, and the other parallel to it.

We see, therefore, that when there is no vertical force to be taken into account, the situation of the point found has no relation whatever to that of the centre of gravity; and when there is a vertical force, the higher the centre of gravity is situated the lower will be the point found by this experiment, and *vice versa*.[1]

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[1] If these observations be not sufficiently clear, they may be rendered so by reference to a diagram.

Let the vertical plane passing through the two inclining forces $a\,b$, $c\,d$, Fig. 12, cut the longitudinal axis passing through the centre of gravity in the point o. To this plane the vertical force arising from the resistance of the water is transferred. The horizontal force necessarily acts in this plane. r is the point in which the resultant of these two forces cuts the longitudinal plane passing through the middle of the ship, and to which point they are transferred. $r\,m$, $r\,h$ represent those forces when the ship is inclined by the force $a\,b$; and $r\,n$, $r\,k$, when she is inclined by the force $c\,d$. $r\,m$ and $r\,n$, for the reason before given, are equal to $a\,b$ and $c\,d$ respectively, and $r\,h$ and $r\,k$ unknown.

Mr. Major assumes:—

$a\,b \,.\, a\,o \,.\, \cos\theta = c\,d \,.\, c\,o \,.\, \cos\theta$, θ being the angle of inclination.

Dividing both sides by $\cos\theta$, substituting $(a\,o - a\,c)$ for $c\,o$, and transposing,

$$a\,o\,(c\,d - a\,b) = c\,d \,.\, a\,c$$

$$a\,o = \frac{c\,d \,.\, a\,c}{c\,d - a\,b}.$$

Now the true equation is,

$$a\,b \,.\, a\,o \,.\, \cos\theta - r\,m \,.\, r\,o \,.\, \cos\theta - r\,h \,.\, r\,o \,.\, \sin\theta =$$
$$c\,d \,.\, c\,o \,.\, \cos\theta - r\,n \,.\, r\,o \,.\, \cos\theta - r\,k \,.\, r\,o \,.\, \sin\theta$$

By transposing $r\,k \,.\, r\,o \,.\, \sin\theta$, dividing by $\cos\theta$, and substituting for $r\,m$ and $r\,n$ their equals $a\,b$ and $c\,d$,

$$a\,b \,.\, a\,o - a\,b \,.\, r\,o + (r\,k - r\,h)\,r\,o \,.\, \tan\theta = c\,d \,.\, c\,o - c\,d \,.\, r\,o$$

By substituting $(a\,o - a\,c)$ for $c\,o$, and $k\,h$ for $(r\,k - r\,h)$

$$a\,b \,.\, a\,o - a\,b \,.\, r\,o + k\,h \,.\, r\,o \,.\, \tan\theta = c\,d\,(a\,o - a\,c) - c\,d \,.\, r\,o$$

In No. I of this work, page 15, we meet with the following method for finding the centre of gravity :—

"Another method proposed for finding the centre of gravity is by causing the ship to roll, by the crew going together from side to side, and having persons in boats at the stem and stern-post, to observe the points that do not partake of a circular motion, which are the poles of the axis of rotation, which passes through the centre of gravity of the ship."

It is then added, "There is, however, a difficulty in observing these points on account of the rising and falling of the centre of gravity, in consequence of the inclination."

This case is the reverse of the other, in which the rotatory

Or, $(a\,o - r\,o)\,(c\,d - a\,b) - k\,h\,.\,r\,o\,.\tan\theta = c\,d\,.\,a\,c$

Dividing by $(c\,d - a\,b)$ and putting $a\,r$ for $(a\,o - r\,o)$ we have,

$$a\,r - \frac{k\,h\,.\,r\,o\,.\tan\theta}{c\,d - a\,b} = \frac{c\,d\,.\,a\,c}{c\,d - a\,b}$$

If $\dfrac{k\,h\,.\,r\,o\,.\tan\theta}{c\,d - a\,b}$ be so small that it may be neglected, then

$a\,r = \dfrac{c\,d\,.\,a\,c}{c\,d - a\,b}$ nearly. Hence, in this case, instead of the distance of the centre of gravity from the point a being equal to $\dfrac{c\,d\,.\,a\,c}{c\,d - a\,b}$, we see that this expression has no relation to the situation of the centre of gravity, but to that of the point where the resultant of the water intersects the longitudinal plane passing through the middle of the ship. If $\dfrac{k\,h\,.\,r\,o\,.\tan\theta}{c\,d - a\,b}$ be too great to be neglected, then the point determined by this experiment will be above the point r, as was before stated; and *cæteris paribus*, the lower the centre of gravity is, the higher will be the point determined, and, therefore, the farther removed from it.

If the resultant of the water pass below the centre of gravity, the expressions for the effect of the vertical and horizontal forces will be positive instead of negative; in other respects the same process is applicable, and similar conclusions will be arrived at.

force, brought into operation in consequence of the rectilinear motion, was neglected. Here the rectilinear motion, caused by the resistance of the water in consequence of the rotatory motion, is neglected. This resistance would cause the centre of gravity to move from side to side; so that the fixed point, if indeed any point be fixed, must lie higher than the centre of gravity.

Independently of this consideration, the experiment would be inconclusive, in as much as the situation of the centre of gravity itself is continually altered by the crew going from side to side.

It has been shown that if, by means of any force which is not vertical, a ship be made to incline, the lateral motion causes a horizontal and a vertical force to be brought into operation. The degree of inclination must evidently depend, in some measure, on the quantity and direction of their resultant.

Atwood, however, says, in page 305 of his "Philosophical Transactions," 1798:—

"It is here necessary to observe, that the force of stability and the measure of it, the subject of investigation in the preceding pages, is wholly independent of the water's resistance, which co-operates only while it is inclining, and wholly ceases as soon as the vessel has attained to its greatest inclination, at which it is supposed permanently to remain in a state of equilibrium, the inclining force being exactly balanced by the force of stability. This observation will obviate any difficulty that might possibly occur from the principle stated in page 213; which is, that if the zone W H F C,[1] comprehending that portion of the sides of a vessel which may be immersed under, and may emerge above the water's surface, should be the same in two vessels, the stability will be the same at all equal angles from the upright, whatever shape be given to the form of the volume immersed, which is situated beneath the said zone, provided the vessels be in other respects similarly constructed and adjusted: if, for instance, the keel of one vessel should be very deep under the body of the vessel, the keel of the other being

[1] This will be easily understood without a figure.

of the ordinary dimensions, the deeper keel will oppose an increased resistance to the inclination of the vessel only while it is inclining, so as to make it heel slower; but will not alter the angle of permanent inclination caused by a given force of the wind, or other uniform power: which inclination depends entirely on the stability which has been determined in the preceding pages, and has no relation to the resistance of the water, which arises from the vessel's inclination round its longer axis."

It is true that the resistance of the water does not affect the *stability*, but it affects the *inclination* of the ship, which, in a practical sense, is the same thing; and of two ships with the same masts and sails, the one which, with the same force of wind, inclines to the less angle, may be said to possess greater stability than the other.

But Atwood not only says that the stability is not affected by the resistance of the water, but also that it "wholly ceases as soon as the vessel has attained to its greatest inclination." The resistance occasioned by the rotatory motion of course ceases with that motion, but the resistance occasioned by the lateral motion always exists; which resistance most certainly would alter the angle of permanent inclination, unless the line of mean resistance passed through the longitudinal axis passing through the centre of gravity of the ship.

It is also said, that the only effect produced by a deep keel under a vessel will be "to make it heel slower, but will not alter the angle of permanent inclination caused by a given force of the wind, or other uniform power." Now, a deep keel not only increases the lateral resistance, but it causes the line of mean resistance to pass through a point at a greater distance from the inclining force. For which reasons such a ship, under all circumstances, must incline at a greater angle than one which has a keel of the ordinary dimensions.

If the effect produced on the inclination by the resistance of the water needed any farther illustration, we may suppose a prism, generated by the motion of an isosceles right angled triangle, to be so placed in the water that the side generated by the base of the triangle may be in the plane of the water's surface. Let it move laterally. If there be no inclination, the

mean resistance will pass through the line formed by the intersection of the plane of the water's surface with a vertical one bisecting the prism lengthways. The mean resistance on a vertical plane, immersed the same depth as the prism, would pass through a point half its depth below the surface of the water. Hence in producing inclination, the effect of the same inclining force at the same height above the water's surface, and acting in conjunction with the resistance of the water, would be less in the former case than in the latter, by the force multiplied by half the depth of the plane, or of the prism.

We see, also, that the effect of a similar force brought into operation by the ship's moving in the direction of her length is such, that an horizontal force in the same direction, applied at a point at a considerable height, the *point velique* produces no depression.

Art. III.—*Observations relative to the late experimental Cruises of Ships of War, with a view of showing by what means a future experimental Trial of Ships may be rendered subservient to the advancement of the Science of Naval Architecture.* By Mr. William Henwood, *of his Majesty's Dock-yard, Portsmouth.*

An account of the principal dimensions of ships of various classes in the British navy, given by Mr. Bennett in the fifth Number of this work, sufficiently shows that the lengths and breadths of ships of war have always been determined in a purely arbitrary manner. It does not appear that any well-recognised principle or rule has hitherto been either propounded or adopted, for the guidance of constructors of ships, in fixing on the length, breadth, and depth of a vessel. The old method, of making a ship a little longer, or a little broader, or, possibly, a little deeper, or the reverse, than some favourite French, Swedish, American, Spanish, or Dutch ship, has been universally followed by English ship-builders.

It appears highly desirable we should endeavour to discover

and fix the limits beyond which the length and breadth and depth of a ship should not be carried. This, it is considered, can be done in no other way than by instituting a much more minute and strictly scientific comparison between ships of the same class, of different dimensions, than has ever yet been done. It is perfectly certain we possess the means of finding out the causes of those palpable differences in the performances of ships at sea, which excite surprise and amazement in many individuals, and dispose them to conclude the subject is involved in impenetrable mystery. All that can be required is, that the knowledge we are already in the possession of should be fairly brought into play, and allowed full scope for its exercise.

It is much to be regretted that so very few facts have been elicited by the several recent experimental cruises of our ships of war. The causes of this circumstance appear to the writer to be a subject deserving of minute inquiry and full exposition. The expense of sending a number of ships to sea, for the express purpose of finding out which is the fastest sailer, or the best ship, is so great, that if any method can be suggested to ensure the obtaining a satisfactory result from any future trial of the sailing qualities of ships, it is to be hoped it will meet with the attention it may deserve.

The experimental trials of the Orestes, Champion, and Pylades, corvettes of 18 guns, in the years 1824 and 1825, terminated, unfortunately, before it had been so fully ascertained, as was to be desired, which of the three was the best ship. The result of the first cruise was, that the Champion was, on the whole, rather the best of the three. Several alterations were made in the other two ships, previously to their sailing the second time, but no alteration was made in the Champion :—she sailed the second time precisely as she did the first; and she was, through this circumstance, a standard of comparison by which the good or bad effects of the alterations made in the other ships could be manifested. At the end of the second cruise, it was most obvious that both the Orestes and the Pylades had been exceedingly improved by what had been done to them; and that the Orestes was decidedly the best ship of the squadron. Previously to the third cruise, all the ships were altered, and no standard of comparison was preserved; and the result of the

third cruise was, in consequence, rendered altogether a matter of uncertainty. Had no alteration whatever been made in the Orestes after the second trial, it would have been proved whether what had been done to the Champion, and the Pylades, had been productive of benefit, or the contrary.

A similar want of a test, by which the good or the bad effects of the alterations made in the ships of the experimental squadron of 1827, (of which an account was given by Mr. Bennett, in the article above referred to, and by Mr. Chatfield, in the seventh Number of this work,) appears to have existed. It was stated in No. 73 of the "Quarterly Review," relative to the result of the trials of this squadron, that the gallant admiral who commanded it would not decide which of the ships was better than the others. Reflection on these and other circumstances, which need not be mentioned, has led the writer to conclude that it would be possible, in a future trial of rival vessels, to obtain a satisfactory and indisputable account of the relative merits of a number of ships, if the following considerations and mode of proceeding were to be attended to and observed.

It is essentially necessary that all the ships of an experimental squadron should proceed to sea as nearly as possible under the same circumstances. They should carry the same proportion of stores and other weights, with the exception of ballast, the quantity of which must be sufficient, in conjunction with the other weights, to produce the desired degree of stability. The bottoms of the ships, also, should be equally clean; and the officers to command them should be selected solely on account of their professional ability. Unless these particulars are attended to, it is vain to expect satisfactory and accurate results from an experimental cruise.

But there are other considerations which especially demand the attention of those who aim to find out the relative excellence of ships in sailing. It is well known that a fore-and-aft rigged vessel has a great advantage over a square rigged vessel in sailing by the wind. And there is every reason to believe the superior sailing of the Columbine by the wind, during her experimental cruising, was owing, in a great degree, to the means afforded her of bracing her yards so very much nearer to

the fore-and-aft direction than any other vessel of the squadron could do. Mr. Bennett has stated, in his paper above referred to, that "the Columbine's main-yard was braced to an angle of 19°, and frequently to an angle of only 17°;" and that "the angle to which the main-yards of most of the ships of the squadron were braced, when sailing close-hauled, varied between 27° and 30°. The Columbine's sails appear therefore to have been trimmed somewhere about ten degrees nearer the fore-and-aft direction, than the sails of the other ships of the squadron. This difference in the angles to which the sails of those ships were trimmed is so great, that it is most deeply to be regretted, when so favourable an opportunity presented itself of ascertaining a most important question,—whether the fast sailing of the Columbine was or was not mainly owing to the unusually sharp bracing of her yards,—the circumstance should have been allowed to pass unregarded. If any of the other ships of the squadron, which were not deficient in stability, had had the same means afforded them of bracing their sails to the same angle as those of the Columbine, it is highly probable the latter ship would not have appeared to so great an advantage as she is said to have done. The advantage obtained from bracing the yards sharp, would very possibly be neutralized in a crank ship, by the increased heeling which the sails, when so trimmed, would necessarily occasion.

It is also well known that many ships have been much improved in sailing by the wind, through an additional depth of keel. The beneficial effect of an increased depth of keel, in preventing a ship from falling to leeward, was most clearly evinced in the Pylades, during the second and third experimental cruises of 1824 and 1825. This ship was remarkably leewardly during the first trial; and was rendered quite as weatherly as either the Orestes, or the Champion, by an addition of 12 inches of depth to her keel. There was no other alteration made in the Pylades, which could have produced the very great difference there was, during the last two cruises, in her sailing by the wind.

The resistance to leeway must certainly depend on the area of the vertical and longitudinal section of a ship under the water. And, so far as we know, the ordinary differences in the

forms of the bottoms of ships of the same size, can have but very little, if any, effect in increasing or in diminishing the lateral resistance. We may, in general, safely leave the form of the ship out of the question, and assume that the resistance to leeway depends on, and is proportionate to, the mean length of the ship below the line of floatation, multiplied by the mean draught of water. If ships of the same class have not the same means afforded them of opposing leeway, one ship may always be found to sail faster than another, when sailing off the wind, and to be very leewardly in comparison with the same vessel when close hauled; whilst nothing but an additional false keel is wanting to make her in all circumstances the fastest and most weatherly ship. It accordingly appears to be of importance, that in a future experimental squadron, all ships of the same class should be required to have such a depth of false keel as will make the product of the mean length, and the mean depth of the immersed part of the body, equal, or nearly so, in them all. Were this condition to be made indispensable in a future experimental squadron, it would be proved which of the ships met with the least *direct* resistance; and this is the point the most desirable to be correctly ascertained.

Having stated what appears of principal importance to be attended to, in fitting out ships for a trial of sailing; a few observations will now be offered with a view of showing how it is considered to be quite possible to arrive at a more precise and satisfactory conclusion respecting the comparative merits of rival ships, than has in any instance been obtained from an experimental squadron. It has almost invariably occurred after a number of ships have returned from a trial of their sailing, some degree of superiority has been claimed by almost every one of them, which has not been acknowledged by the others.

A discrepancy in the opinions formed by different individuals respecting the comparative sailing qualities of ships, appears to arise out of the difficulty of correctly determining distances at sea; and the difficulty of accurately estimating the apparent loss of some ships, and the apparent gain of others, occasioned by a shift of wind, so as to be able to make a just allowance for such apparent, though unreal, loss of some, and gain of other ships.

The difficulty of judging satisfactorily how far distant any ship is from another at sea, is notorious. It is well known that objects, whether viewed on land or at sea, appear nearer or more distant than in reality they are, in proportion as the atmosphere is more or less clear. It is also well known, we form a judgment of the distance of an object from us, when one or more objects intervene, very different from that which we form when nothing intervenes. Philosophers have long since remarked, that the sun or the moon when seen by the naked eye near the horizon, appears much nearer to us than when beheld through a tube which cuts off the view of the intermediate houses, trees, ships, or other objects. It is not to be expected that persons who do not take these things into the account should be enabled by practice to judge correctly of considerable distances at sea. Short distances may on most occasions be estimated by practised observers with sufficient accuracy for general purposes; but as the correctness of the judgment or opinion of an individual may always be questioned, the usual mode of judging or guessing distances at sea should not be allowed in a trial of the sailing qualities of ships, where accuracy and certainty are so very desirable. Nothing of the kind would be tolerated in a horse-race; and surely such a fallacious way of arriving at a conclusion respecting the relative characters of ships, should not be adhered to if a better can be followed.

To manifest the propriety of making due allowance for the advantage which one ship may seem to have obtained over another by a shift of wind during a trial of sailing, it is only necessary to observe, that if two ships, A and B, which sail equally well, are close hauled, with the wind, for example, at east, A being five miles to windward of B; if the wind changes from east to north, A will appear to have lost five miles to windward, when, in fact, both have sailed equally well. This would be the case whether the wind changed suddenly, or very gradually. The writer does not suppose that when so great a change takes place as 90°, in the direction of the wind, some allowance is not in general made by naval officers for such an occurrence; but he is disposed to believe, when less palpable changes happen, they are frequently either altogether disre-

garded, or their effects on the apparent performances of rival ships are not duly appreciated. If the following suggestions were to be attended to in a future trial of the sailing qualities of a number of ships, it is believed the relative excellence of the vessels would be most clearly and satisfactorily ascertained.

Usually, in a sailing match, the vessels close in a certain order at the commencement of a trial. Each vessel has then a fair opportunity of measuring with trigonometrical accuracy the distance of the nearest ship; and can also observe with precision the bearings of all the ships. Every ship should do this at the same time, and should afterward keep a minute and exact account of her own rate of sailing, and of the direction of her course. The bearings of all the ships should be taken, and the distance of the nearest measured, at certain given periods during the trial, by every ship. Each of the ships should also note particularly the time at which a change of wind is observed to happen, and at the same instant should observe the bearings of all the others, and measure the distance of the nearest. The same should be done whenever the ships tack, or when they purposely alter the direction of their course, and also at the time of the termination of the trial.

Such an account of every trial should be furnished by each ship at the end of the cruise; and a good draughtsman should be employed to make a chart or drawing of the courses of the ships on each trial, first placing them in their relative positions at starting, and then tracing the course of each ship from her starting point, according to the statements given of her course and rate of sailing. A moment's reflection will make it quite evident that, by having the bearings of each ship observed by all the rest, and the distance of the nearest, determined by each, at the same instant, any slight inaccuracy in an observation made on board one ship, would be immediately discovered and rectified by the concurrence of the observations made on board the others. The bearings of any number of objects can be most accurately observed in a very short time, however distant they may be; and the distance of the nearest ship can be measured with much greater certainty than that of the more remote. The intersections of the bearings of the several ships, being found to accord with the measured dis-

tances of the nearest, determined by each ship respectively, will always fix the positions of the ships with the utmost precision. This method will also prove how nearly the rate of sailing had been correctly found and reported by each; and whether the ships had measured with exactness the distance of the nearest in every instance. A perfect chart of each trial could thus be made; and if this were to be done in a future experimental cruise, it would be unnecessary to ask any one which ship sailed the best. The charts would show which had sailed the fastest, which faster than another, and in what degree; and an opinion about the matter would be altogether superfluous and inadmissible.

The very great importance of accurately ascertaining the characters of ships as slow or fast sailers, appears from the consideration that it is impossible we can assign the best proportion between the length and breadth of a ship, until we become possessed of this knowledge. We have, it is true, some facts upon which we feel justified in grounding an opinion on this subject; but we have nothing sufficiently well ascertained and attested, to satisfy us it is impossible, the conclusion we have been brought to, that our ships in general ought to be considerably broader than they are, can be wrong. An instance of this almost satisfactory kind of evidence, that our ships of war ought to be broader, has been furnished by the recent trial of sailing between the Winchester, a fifty-two gun frigate, and the Barham, a cut down seventy-four. The Winchester appears to have established for herself the character of a very fast sailing ship, and there seems to have been no want of proof that the Barham sailed much better after she had been cut down than she did before. It was therefore to be expected that these ships would not be found to sail very unequally. And from the short trial which took place, it appears to have been found, the two ships sailed so nearly alike when by the wind, that it could not be asserted one was superior to the other; and in sailing with the wind abaft the beam, the Winchester was rather the faster sailer of the two.

The lengths of these ships, and their sailing draughts of water, are very nearly the same; but their breadths, and the weights of their hulls, and the forms of their bottoms, are very

different. The Winchester is 173 feet long, 43 feet 9 inches broad, and her mean draught of water is 20 feet. The weight of her hull is about 1000 tons; and the form of her bottom is defined by a very rising floor, a tolerably large area of floatation, a pretty sharp after body, and a rather unusually fine fore body. The Barham is 176 feet long, 47 feet 6 inches broad; her mean draught of water is 20 feet 3½ inches. The weight of her hull is about 1420 tons; and the form of her bottom is defined by a flat floor, a rather less area of floatation, in proportion to her breadth, than the Winchester, and greater fulness of the fore body. The quantity of sail carried by these two ships is very nearly the same; and the angle of bracing the yards cannot be very different. The Winchester being the narrowest ship, has probably (though it is neither proper nor unavoidable that a comparatively narrow ship should have) a slight advantage in this respect.

The great and palpable differences between these ships are in their breadths, the weights of their hulls, and the forms of their bottoms. The greater weight of the Barham's hull (which is owing to her having been originally a two-decked ship), and her consequently greater displacement, must have operated as a considerable drawback to her velocity in sailing; and the form of her bottom, being that which was adopted first by the French, on the erroneous supposition that a flat deep floor gives great stability, and which form has been copied from the French by the constructors of the British navy, who have doubtless supposed it the *ne plus ultra* of excellence, is that which all constructors of ships, whether scientific or unscientific, appear now to consider and to have abandoned as the worst calculated for fast sailing. Whence then does it arise that the Barham is as fast, or nearly as fast, a sailing ship as the Winchester? Every difference between them, except that of the breadth, which can be supposed to affect their sailing qualities, must have been prejudicial to the Barham. To what then can the good sailing of the latter, in comparison with the Winchester, be attributed so much as to her being nearly four feet broader, and to her having an area of floatation greater by about 400 feet than that of the Winchester, and to her possessing in consequence a greater degree of stability?

Another reason why the Barham, a ship so much heavier than the Winchester, was moved as fast, or nearly as fast, through the water by the same quantity of sail is, that the fulness of the fore body, and the fineness of the after body, were greater in the Barham than in the Winchester; so that the advantage which the latter had over the former in the form of her bottom by the rise of her floor, was, in all probability, nullified by the disadvantage of her fore body being less full than it ought to be, and her after body less fine. The importance of a due degree of fulness to the fore body, and fineness to the after body of a ship, may be strikingly manifested by a comparison of the Winchester with the Java, another 52-gun frigate, of very nearly the same length, breadth, depth, and displacement.

The Java is known to be a decidedly bad ship. It has been stated by those who sailed in her, that in a sea at all rough she labours extremely, in comparison with other ships, and pitches with the utmost violence. The sole difference between the Java and the Winchester, is in the relative fulness of their fore and after bodies. The Java is considerably finer forward and fuller abaft than the Winchester: in other words, the centre of gravity of displacement in the former, is farther aft than the same point in the latter. And the consequence is, that although the ballast may be placed very far aft, which it must be in the Java, to bring her to the best sailing trim; yet the momentum of the weights at the bow being as great as in a ship with a full fore body, and there being so inadequate a support for those weights at the great distance at which they are situate afore the centre of gravity of the ship, they must act with immense mechanical advantage to augment the force of the pitching motion. The pitching of such a ship as the Java must necessarily be most violent and prejudicial to her sailing; and several of our ships of war are, unfortunately, such ships.

It is much to be regretted that this ship, which in the course of the repair she has been for some time past receiving, might, at a very trifling expense, have been made almost a *fac-simile* of the Winchester, and possibly even a better ship;—for the latter, as was above intimated, has rather too fine a fore body,—has been repaired so as to preserve all her old well known bad

qualities, and will, of course, be always just as laboursome and slow-sailing a ship as she ever has been.

A comparison might be made between some other ships which would lead, it is believed, to the same conclusion as that which has been derived from comparing the Winchester and the Barham;—that an increase of the breadth of our ships of war would make them better sailers. Until the contrary shall have been proved by actual experiment, it must continue to be doubtful, whether our ships of war in general, might not with great advantage to their sailing qualities be made so broad that they would have a sufficient degree of stability without the use of more than a very small portion of the usual quantity of ballast.

A brief reference may here be made to our men-of-war brigs. The 18-gun brigs have generally been considered, for their size, the finest class of our ships of war; and of all the ships of our navy, with the exception of the Columbine, these vessels have the greatest breadth in proportion to their length. The 10-gun brigs, on the contrary, have been characterized as one of the worst classes of our vessels of war; and as these brigs are very similar in form to those of 18 guns, and are much narrower in proportion to their length, their acknowledged inferiority can be ascribed to nothing so much as to their want of greater breadth. The 10-gun brigs are 3,67 times as long as they are broad, whilst those of 18-guns are in length only 3,27 times their breadth. As it is a perfectly well established principle in naval architecture, that a small ship should be broader, in proportion to her length, than a large one; if the brigs of 18 guns are not too broad, those of 10 guns are much too narrow.

It is only by experiment the best proportion between the length, breadth, and depth of a ship can be ascertained. It is, therefore, highly desirable that a few ships, of different classes, of great breadth, should be built; and their good or bad qualities as ships of war submitted to the most rigid and scientific scrutiny. A brig or a corvette might be in length just three times her breadth; the length of a frigate might be $3\frac{1}{4}$ times her breadth; and a ship of the line $3\frac{1}{2}$ times. Ships built with these proportions of length and breadth, with the centre of gravity of displacement sufficiently far forward, could not but be good ships; and if they were to be made of that form, ich, in Art. 32 of the last Number of this work, was shown

to be the best adapted both for velocity and stability, it is in the highest degree probable they would be very decidedly superior to any ships which have yet been built.

ART. IV.—*Notice of a Pamphlet "On the Advantages of observing a Ship's Inclination at Sea, &c., by Henry Chatfield, of his Majesty's Dock-yard at Plymouth, Member of the School of Naval Architecture."*

THIS little pamphlet contains many valuable observations on the present state of naval architecture, and its future improvement. No subject is more dependent on correct accounts of experience than this, and perhaps in none are the registered accounts of experience so vaguely expressed. The principal cause of the little improvement in the design of ships, is the want of the union of mathematical and experimental knowledge. It is too much the practice to consider theory and experience as opposed to each other; and while the importance of the latter is universally admitted, the advantage of the other is too frequently neglected. We would not extol the benefits of theoretical knowledge by lowering the utility of experimental knowledge; much less would we prefer the isolated observations of experience, and such they must be without the connexion science alone can give them, to the certain rules of theory, founded on the known laws of nature. The combination of theoretical and experimental knowledge is necessary for the improvement of the design of ships.

If this be allowed, the question arises, In what manner can this combination of knowledge be obtained? Theoretical knowledge requires an education in mathematical science and natural philosophy, to be obtained only by an undivided attention to it for many years. Such observations on the qualities and behaviour of ships, as are necessary to constitute an experience useful in design, can be obtained only by a long service at sea. The attainment of these two kinds of knowledge in the same person, by his own application and observation, is incompatible: each requires a long experience, and each must

be obtained by a different process. The necessary acquaintance with mathematical knowledge and natural philosophy may be obtained by any man of ability and application devoted to the pursuit; but the necessary knowledge to be derived from observation, requires an experience at sea in many classes of ships under various circumstances: this experience must be the result of the observations of many. The legitimate use of this knowledge obtained by observation, is its being subjected to examination and comparison, according to the known laws of mathematical science. The only practical means of rendering this combination of knowledge applicable to the improvement of naval architecture, appears to be by collecting together the reports of naval officers on the qualities and behaviour of ships under all circumstances at sea, for the use of the naval architect. In this manner experimental and theoretical knowledge may be combined with complete advantage.

To render the reports of naval officers on the qualities and behaviour of their ships as useful as they are capable of being made, it is necessary that the information they contain should be clear and definite. Mr. Chatfield, in his pamphlet, particularly insists on the necessity of this correct method of stating the results of naval observations. He observes, "Questions which are to be made applicable to science should convey our ideas in definite terms, and in order to effect this, we must adopt legitimate language. Speaking of rotatory movements, for instance, the appropriate term is degrees; distances should be expressed by linear measurement; and intervals by divisions of time, &c."

Mr. Chatfield shows the great importance of having the inclination of a ship, under different circumstances at sea, correctly observed and registered, by means of a nauropometer, an instrument made for this purpose. The proper degree of stability of ships to be designed, and their correct masting, as well as the alteration of the stability of ships already built, by means of stowage, and of their masting, depend on such observations. He remarks, with justice, the little advantage which can be derived from such terms as, "crank—stiff—well—pretty well," &c., in answer to the question, "How does a ship stand under her canvas?" and of "low—rather low—very low," &c., to the question "How does she carry her

lee-ports?" and of "deeply—quickly—easily," &c., to the question "How does she roll?" The terms are vague, and almost useless for the purpose for which they are intended; instead of the answers being expressed by measurement—by the number of degrees through which the ship inclines, they merely give a general notion of the ship's behaviour, dependent entirely on the opinion of the officers, and the arbitrary meaning they may attach to the terms they apply.

Mr. Chatfield's pamphlet contains some valuable remarks on the necessity of knowing the inclination of a ship under different circumstances, in order to point the guns correctly. He observes, "To explain the application of these remarks, let the inclination under different conditions of weather be carefully registered, noting the quantity of sail set in all cases; and let experiments be made on the effects produced by shortening sail in discretionary proportions; such proportions, for instance, as would be likely to take place according to the circumstances under which it might be deemed expedient to engage an enemy. The inclination of a ship under a given quantity of sail, will of course vary according to the strength of the wind; consequently, the number of degrees that a vessel will right herself by taking in certain sails, will vary in a similar proportion, which must be tabulated with great care. The rate of sailing will also vary, which should likewise be noted, and the whole inserted in a table of the following description:—

Ship's inclination.	Sails set.	Rate of sailing.	Remarks on the weather.
—°	Courses, topsails, top-gallant sails, jib, f. topmast stay-sails, spanker.	— knots.	
—°	Courses hauled up.	— knots.	
—°	Top-gallant sails struck.	— knots.	

The above experimental table is the result of observations made on board the ——, between dates —— and ——, on a voyage to and from ——. The vessel was stored and provisioned for —— months.

Captain.
Master.

"If trials of this kind were carefully conducted, it is evident, that whenever a ship was under sail, and an engagement contemplated, nothing could be more simple than to observe the ship's inclination; and then, by referring to the recorded properties, ascertain the effects that would be produced by trimming the sails in any desired manner. This may be done at any period before the time of action, so that there need be no hurry or confusion on the part of the individual on whom it devolved, to direct the adjustment of the guns, nor on the part of the men at their stations. A very small tablo of results, made out on a few (about three) occasions, when the strength of the wind produced a sensibly different effect on the ship's inclination, might be placed near the nauropometer, from which it would be immediately seen to what angle the ship would be depressed in the cases of hauling up the courses, striking top-gallant sails, &c.

"Having ascertained this point, it only remains to elevate or depress the entire of the guns, through exactly the same angle, and fix upon the distance at which it is intended to commence firing; the sight may then be adjusted accordingly, and aim taken by its use; or, as many degrees may be added to or deducted from the ship's inclination, as are *due to the distance* of the object fired at, unless the distance is to be left to circumstances."

Mr. Chatfield proposes a new "coin on geometrical principles, to elevate or depress the guns with perfect accuracy, through every degree within the prescribed vertical range."

The pamphlet concludes with observations on naval construction, in which is shown the advantage which might be expected to arise from an "office of construction." We have long intended to offer some remarks on this subject, which we shall now briefly allude to, and resume at a future opportunity. The education necessary for the qualification of a naval architect is different from that which is necessary for a practical builder. The education of a practical builder requires a considerable acquaintance with mechanical and chemical science; of the former, to proportion correctly the strength of materials to the strain to which they will be subjected, and to apply the fastenings in the best manner to sustain the action of the forces

to which they are opposed, so that a sufficient strength may be afforded to the fabric with the least expenditure of materials; and of the latter, to avoid bringing into chemical action substances which contact might render destructive to their durability. We would not confine within too narrow limits the education of the practical builder—the strains to which ships are exposed are, in some cases, difficult to estimate; but experience, derived from the examination of ships come home, after having been long at sea, and exposed to severe gales, will greatly assist the practical builder, in determining what parts require additional strength, which his mechanical knowledge may supply. The naval architect requires a much more extensive acquaintance with mathematical science and natural philosophy;—he needs a life devoted to the design of ships, to which all his pursuits should be directed. The experience of building and repairing ships does not prepare a man for the design of ships: the pursuits are widely different, and the previous education and habits should be in accordance with those objects.

The office of construction would concentrate all the information which could be obtained on naval design; it would collect the reports of naval officers on the qualities and behaviour of their ships, as well as the results of all experiments made in this and other countries connected with naval design. A perfect acquaintance with the different systems of design used in other countries should be possessed by the members of this office, in addition to a competent knowledge of mathematical science and natural philosophy. A most important duty which would devolve on this office, would be the formation of a complete digest[1] of the elements of the ships of the British navy, and of all other ships of which the drawings and the reports of their qualities could be obtained.

If at one period more than another such an office of construction might be expected to be advantageous to the interests of naval architecture in this country, it is at the present, in which a new system of naval construction opens on us,—the use

[1] See Mr. Major's proposal for making a digest of the ships of the Royal navy, in the "Annals of Philosophy," November, 1825.

of steam-vessels in naval warfare. There is comparatively but little known on this subject; and it is to be expected that the next war will require a great change in the system of naval construction, to meet the exigencies of new circumstances. Mr. Chatfield observes on this subject, "There is not sufficient analogy between a sailing man-of-war and a steam-vessel, intended for the same service; to class them as bodies whose elements are determinable by the same laws and principles; experience in the one can hardly be called experience in the other; and they are so dissimilar, that a naval architect, in other respects tolerably conversant with construction, might fall into serious errors in designing a steam-ship. Great attention must now be given to this subject, which opens a new and wide field for inquiry; otherwise it will always be attended with speculation, to go beyond what has been done before. Imitating is certainly a safe mode of proceeding; but it is more creditable, and in every sense more desirable, to be able to rely entirely on our own resources; and a naval nation, naturally aspiring to excellence, should never stop short of that degree of perfection which is obviously within reach."—"We are now certainly only beginning a system; it must, therefore, be our object to establish laws and fixed principles relatively to this branch of nautical science, to guide us through the difficulties that may hereafter attend a much more enlarged plan of building than we have yet tried."

A just tribute is paid in this pamphlet to the talents and knowledge of Professor Inman, to whom this science is more indebted than will perhaps be generally known in the present age. He has divested it of all the speculation and mystery which many have in past years endeavoured to throw round it. He has placed it on the same footing as other departments of natural philosophy; and shown that improvement is only to be obtained by subjecting all the elements of naval design to the known laws of mechanics, and by examining the designs of ships by the reports made on their behaviour at sea. By comparing the calculated elements of ships in this manner, the alterations necessary to improve future designs are discovered; errors are corrected, and deficiencies supplied; and in accord-

ance with the service for which particular ships are constructed, their improvement is gradually and certainly carried forward.

What has been so well begun by the Professor, under the liberal patronage and directions of Government, we trust will be successfully carried forward by the members of the School of Naval Architecture, who have been expressly educated by him for this object. We are naturally anxious to see the merits of this establishment brought to this test; and we are sanguine in our hopes, that the result will fully answer the object which is intended to be obtained, the improvement of the design of the ships of the royal navy.

ART. V.—*Notice of "Scales of the Displacements; and of the Areas of the Horizontal and Vertical Sections; and of the Areas of the external Surface of the several Classes of Ships composing the British Navy, &c., by William Parsons, of his Majesty's Dock-yard, Portsmouth, Naval Architect, formerly a Student of the School of Naval Architecture."*

THE principal object of this work is "to point out the fallacy of the present method of ascertaining the register tonnage of ships, and to suggest another founded on correct principles."

That the present rule does not give the true tonnage, or the quantity of lading a ship can carry, has been long known; probably from its establishment; the opportunity it affords of defrauding the revenue, by constructing ships to carry more than their computed tonnage, has been repeatedly shown; and the effect this has had on the forms of merchant ships, by the sacrifice of good sailing properties to the capability of taking excessive ladings, has been found in numerous instances to be most injurious.

"The rule at present in use for computing the tonnage, as established by the 13th Geo. III. cap. 74, is this: 'The length

shall be taken in a straight line along the rabbet of the keel of the ship, from the back of the main stern-post to a perpendicular line from the fore part of the main-stem under the bowsprit. The breadth shall be taken from the outside of the outside plank, in the broadest part of the ship, either above or below the main wales, exclusive of all manner of doubling planks that may be wrought upon the sides of the ship.' In cases where it may be necessary to ascertain the tonnage of vessels afloat, by 26th Geo. III. cap. 60, the length is to be taken as follows: 'Drop a plumb-line over the stern of the ship, and measure the distance between such line and the after part of the stern-post, at the load-water mark; then measure from the top of the said plumb-line in a parallel direction with the water, to a perpendicular point immediately over the load-water mark, at the fore part of the main-stem, subtracting from such admeasurement the above distance; the remainder will be the ship's extreme length, from which is to be deducted three inches for every foot of the load draft of water for the rake abaft.'

"Then by 13th Geo. III. cap. 74, and 26th Geo. III. cap. 60: 'From the length taken in either of the ways above-mentioned, subtract three-fifths of the breadth taken as above, the remainder is esteemed the just length of the keel to find the tonnage; then multiply this length by the breadth, and that product by half the breadth, and dividing by 94, the quotient is deemed the true contents of the lading.'"

Mr. Parsons gives several instances in which the fallacy of this rule is made strikingly apparent; and shows that even by calculating the tonnage of the same vessel by the two methods given above, the difference of the results is very considerable. He observes, that by "the draft of water being omitted in the rule, the practice of increasing the depth has become general, by which means the vessels are capable of carrying a greater burden without increasing the register tonnage." He says also, "The omission of the draft of water in the rule is considered as its only defect, such however is not the case; the principal defect is, that the form of the vessel is not taken into consideration. This error in the rule is carried to such an extent at the present time, that the register tonnage of merchant

vessels is generally only two-thirds of the absolute burden. Now this excess depends wholly on the form, and therefore varies in almost every vessel, even of the same principal dimensions: and we have said, the present rule for tonnage is totally independent of the form of the vessel, this excess is wholly exempt from any dues levied by this rule; or if it be observed that the dues are laid on the apparent tonnage, with reference to this excess, the objection is not removed, as the excess is not constant."

The fallacy of this rule is clearly shown by the author of this work; it may however be observed, that when he states, "that the omission of the draught of water in the rule *is considered as its only defect*," he claims the exposure of its fallacy to a greater extent than can be allowed to him. This, with some other defects in the rule, particularly the method of obtaining the length for tonnage, are generally understood; it is acted on in the practice of building merchant ships in the instances he brings forward. Chapman observes, in the rule for tonnage proposed by him, to which we shall refer, "It is impossible to ascertain a ship's actual burden from the principal dimensions, that is, by the product derived from length, breadth, and depth; because two ships may be of an equal length, breadth, and depth, but greatly differing with regard to tonnage, *owing to the greater or less sharpness of the bottom*," &c.

Before we proceed with a description of the scales of tonnage in Mr. Parsons's book, we shall give some of the rules for calculating the tonnage of ships used in other nations, with some other rules proposed for this purpose.

The following is the French rule for measuring the tonnage of merchant ships: "Add the length of the deck taken between the rabbets to that of the straight line of the keel, and take half their sum; multiply this quantity by the greatest breadth at the midship beam, and the product by the depth of hold and the height between the lower and upper decks, and divide the product by 94. If the vessel has only one deck, take the greatest length of the vessel, multiply it by the greatest breadth in midships, and the product by the greatest height, and then divide by 94."

This rule is simple, but very erroneous. It is true that a

certain depth of the vessel is taken as the third dimension, but it is altogether distinct from the depth the vessel is immersed by the lading: the depth from the load to the light water-line. This depth may vary very considerably in two vessels whose lading may be equal: the one may be much deeper than the other by having a greater rise of floor, the total displacements of the two vessels being the same; the depth may also vary from the decks being placed at different heights in the two vessels. The different forms of body are also totally neglected in this method of measurement.

The following is the method of measuring the tonnage of merchant ships in the United States of America; 64th section of an act of Congress, approved 2nd March, 1799:—"That to ascertain the tonnage of any ship or vessel, the surveyor, or such other person as may be appointed by the collector of the district to measure the same, shall, if the said ship or vessel be double-decked, take the length thereof from the fore-part of the main-stem, to the after-part of the sternpost, above the upper deck, the breadth thereof at the broadest part above the main wales, half of which breadth shall be accounted the depth of such vessel; and shall then deduct from the length three-fifths of the breadth, multiply the remainder by the breadth, and the product by the depth, and shall divide this last product by ninety-five, the quotient whereof shall be deemed the true contents or tonnage of such ship or vessel. And if such ship or vessel be single-decked, the said surveyor, or other person, shall take the length and breadth as above directed, in respect to a double-decked ship or vessel; shall deduct from the said length three-fifths of the breadth, and, taking the depth from the under side of the deck-plank to the ceiling in the hold, shall multiply and divide as aforesaid; and the quotient shall be deemed the tonnage of such ship or vessel."

These rules appear to have been derived from the English and French rules: the first, for double-decked vessels, being nearly the same as the English, and the latter, for single-decked vessels, being nearly the same as the French. They respectively possess the inaccuracies of each, with the additional error of being inconsistent with each other.

The Swedish government, in the year 1778, ordered the following rule for measuring a vessel's burden to be used :—

" 1. All mensuration is to be done by the Swedish foot, and the vessel's burden to be marked down in lasts, each to be considered in weight equal to eighteen skeppund iron weight, or eighteen times 320lbs. Swedish. 2. The vessel's length to be measured on the highest water-line, when loaded, from the fore-part of the rabbet of the stem to the aft-part of the rabbet of the sternpost. 3. The ship's breadth is to be measured in midships without-board, close up to the main wale. 4. The height to be measured from the surface of the water without-board, up to that mark which determines how deeply the vessel will swim when completely loaded. 5. Multiply these three admeasurements by each other, and divide the product by 112, should the vessel be of the usual shape, and neither too full nor too sharp at the stem and stern : if the vessel is sharper, the divisor must then be greater : and if fuller a little less, as pointed out to the measurer in the separate instructions. 6. If the necessary provision, water, wood, and utensils, for the voyage should not be on board when the ship is measured, and which weight does not actually belong to the burden that the vessel is measured to carry, then it is necessary to deduct from the calculated burden of lasts as follows :—on a vessel of 350 lasts is allowed 11 lasts deduction ; (corresponding deductions are given for vessels decreasing in burden from 350 to 40 lasts ;) and so on in proportion, in such vessels as are not coincident with the above denomination. But should any of the articles mentioned be on board, the deduction will be less in proportion. 7. Should one or more of the necessary cables not be on board when the vessel is measured, then the following deductions are to be made : for an 18-inch cable 25 skeppund, iron weight. (The deductions for smaller cables, down to a four-inch cable, are specified) 8. Should one or more anchors be wanting, their weight is to be deducted in proportion to the vessel's size. 9. If the vessel's sails are not on board, the deduction from its number of lasts is to be as follows : on a vessel of 350 lasts, 14 skeppund, iron weight. (Corresponding deductions for the sails of smaller vessels, down

to those of 40 lasts, are given.) And less in proportion when fewer sails are wanting. 10. If the vessel is built to carry guns constantly, and that none, or part of them only, are on board, then a deduction for cannon, carriages, gun-tackling, &c. is as follows: for a 12-pounder, with its requisites, 13 skeppund, iron weight (with corresponding deductions for smaller guns). 11. Should the vessel, when measured, have its ballast on board, then that weight must be ascertained, and added to the number of lasts found; but it is best to measure the vessel before it is ballasted, if convenient. 12. The ship's measurer having duly considered the foregoing circumstances, and in consequence thereof ascertained the vessel's proper tonnage to a certain depth, fore and aft, when loaded, he is then to make an entry of the foregoing in the book of admeasurements given him for that purpose, which book is run through and sealed with the seals of the Court of Aldermen and Custom-house: he is also to enter the number of lasts requisite to immerse the vessel, progressively, from one foot at the beginning of the loading till when completed, and also to set down how deep she lies fore-and-aft when unloaded. He is to deliver copies of the same, with specific calculations, admeasurements, and deductions of all this, to the Court of Aldermen and Board of Customs, within two days after measured, that the same may be examined and sanctioned. 13. Should there be any thing to be observed by the parties, the same must be made known at the respective places, within eight days after the delivery, at the expiration of which time the ship's register will be made out, and the approved calculation of the measurer annexed to the same, and to be kept on board as the ship's inventory. The same is to be entered, with all the calculations, in bound paged books, and alphabets thereunto annexed, in the Court of Aldermen and at the Custom-house. 14. Whereas vessels, when old, and soaked through by the water, cannot carry so much as when new, it is therefore requisite to measure the vessel every tenth year, in like manner as expressed in the twelfth section."

In the instructions alluded to in the fifth section, vessels are supposed to be divided into seven classes, according to their fulness or sharpness; and corresponding divisors are given,

which were obtained by calculations made on different vessels, These divisors vary for the whole depth immersed by the lading, from 104 for the fullest, to 122 for the sharpest vessel; and the divisors to be used near the load-water line vary from 98 to 104, and near the light-water line, or discharging line, from 108 to 133.

This rule is very good—strictly correct in principle; the only error which can arise in practice, in ascertaining the lading on board any vessel, is in the divisor being left to the determination of the measurer, dependent on his judgment and honesty. There can be no doubt, however, of a skilful measurer, by great practice, being able to determine the divisor with ease and certainty.

Mr. Parkin, late master shipwright of his Majesty's dock-yard at Chatham, has given two rules for calculating the tonnage of ships, published in "The Shipwright's Vade Mecum:" the one for ships of the Royal navy, and the other for merchant-ships. The following is the rule he has proposed for merchant-ships:—"1. Take the length of the lower deck, from the rabbet of the stem to the rabbet of the sternpost; then take $\frac{3}{3}\frac{1}{2}$ of this length, and call it the *keel for tonnage.* 2. To the extreme breadth add the length of the lower deck; then take $\frac{3}{55}$ of this sum, and call it the *depth for tonnage.* 3. Set up this depth from the limber strake; and at that height, take a breadth also from out to outside of the plank at dead flat. Take another at two-thirds of this height, and another at one-third of the height. Add the extreme breadth and these three breadths together, and take one-fourth of the sum for the *breadth for tonnage.* 4. Multiply the length for tonnage by the depth for tonnage, and the product by the breadth for tonnage, and divide by 36,6666 or $36\frac{2}{3}$, and the quotient will be the burden in tons."

This rule seems to have been formed with considerable labour, and it presents the appearance of a little approach towards the true measurement of the tonnage. It is not, however, founded on correct principles: the elements which enter into the measurement of the true tonnage or lading being given in certain proportions of other elements, which do not bear a constant ratio to them. For instance: for the depth between the light and load draughts of water, a certain pro-

portion of the length and breadth is substituted. The examples given by Mr. Parkin, show that the results of his rule come generally much nearer to the true lading than the present rule ; but it can at best be considered only as the substitution of a less error for a greater.

In the year 1791, the Society in London for the Improvement of Naval Architecture, of which his present Majesty (then his Royal Highness the Duke of Clarence) was President, offered eight premiums for different objects connected with improvements in naval science, one of which was the following :—The Society offer a premium of twenty guineas and the silver medal for the most ready and accurate method, by approximation or otherwise, for determining the tonnage of vessels and ships of every description, from an admeasurement of all the principal dimensions.

The indefatigable and justly celebrated Chapman, who was an honorary member of the Society, sent a paper[1] on the subject which was published in the "Account of the Institution, &c. of the Society," printed in London in 1792.

Chapman gives two rules in this paper : the first is an approximate rule for tonnage, which he considers chiefly in connexion with the payment for the building of ships. He says, "The cost of a ship is nearly in proportion to its outer surface multiplied by the thickness of its sides; but as this thickness may be considered in proportion to one of the dimensions, so it may be judged that the product of length, breadth, and depth, gives the proportional costs. Nevertheless, a difficulty attends this; namely, the length and breadth can precisely be fixed, but the height or depth not altogether so easily. For instance, if I use the depth of the hold as the third dimension, it may happen, in consequence of the cargo which the vessel is to carry, that the lower deck has been laid a foot higher or lower, although its length, breadth, and the whole of the height, remain the same without any alteration ; the expense of building equally the same, as also the burden ; but the difference of the height of the deck increases or decreases the product, and consequently the price in proportion. In like manner it acts with

[1] The Swedish rule given above is taken from this paper.

regard to the upper deck. Should the height of the vessel from the keelson to the gunwale be taken as the third dimension, it will be found to vary as much as the former. For example, the gunwale might be made half a foot or a foot less in height, and that added to the gunwale after the ship is built, which of course would make it cost less than if that height was included in the calculation. If that part of a ship which is immersed when loaded should be taken as the third dimension, then would it depend on how high the water-line stands marked on the draught up to which the ship ought to be loaded, which might also be higher or lower. It is therefore better to institute a rule which, although not totally exact, is still determined, and not subject to disputes or confusion.

"I shall therefore propose, that the ship's height or depth should be taken in a proportion to the two precise or determined dimensions, namely, as the square root of the product of the length and breadth. If now the length and breadth be expressed by L and B, then must the depth be in a certain proportion to $\overline{LB}^{\frac{1}{2}}$ without regarding how great that quantity may be. This ought to be multiplied by the length and breadth; that is, the number of tons shall be as $\overline{LB}^{\frac{1}{2}} \times BL = \overline{LB}^{\frac{3}{2}}$. This expression is a solidity or content which characterises the size of the ship, in which two of the principal dimensions are equally involved. To make practical use of this expression for the purpose of determining a ship's burden in tons, and at the same time that it sometimes agrees with the old method, it will be necessary to find what proportion the breadth bears to the length, agreeably to the old method of determining the tonnage when the contract has been equally beneficial. Suppose the breadth to have been $\frac{53}{200}$ of the length, or the length to be 100 feet when the breadth is $26\frac{1}{2}$ feet. According to the old method :—

$$\frac{\overline{100 - \frac{29}{40} \times 26,5} \times \frac{\overline{26,5}^{2}}{2}}{94} = 301,78 \text{ tons: therefore}$$

$$\frac{\overline{100 \times 26,5}^{\frac{3}{2}}}{x} = 301,78; \text{ where } x = 452. \text{ In consequence}$$

of which the size of the ship in tons always ought to be expressed by $\frac{\overline{L\,B}^{\frac{3}{2}}}{452}$."

This divisor, 452, is subject to the alteration according to circumstances.

The other rule given by Chapman, is for the correct determination of the weight of the lading which a ship carries. This rule is similar to that given by the Swedish government, except that Chapman adapts his divisors to the English ton, instead of the Swedish skippund. He gives a table for 10 classes of vessels according to the fulness or sharpness of their bodies, in which the divisors vary from 39 in the fullest, to 48 in the sharpest vessel. He takes the extreme length on the load-water line, L; the extreme breadth just below the main-wale, B; and the mean depth between the light and load-water line; the product of these three dimensions, divided by D, the variable divisor in his table, gives the lading in tons.

This rule is also strictly correct in principle; but has the same error in practice as that of the Swedish government given above; the determination of the divisor at the discretion of the measurer.

A rule for the measurement of tonnage is given at page 163, vol. i., of this work, in which a near approximation to the true weight of lading is obtained, by multiplying together the length of the load water-line between the fore part of the rabbet of the stem and the after part of the rabbet of the stern-post, the greatest breadth, and the mean depth between the light and load-water lines; taking three-fourths of the product, and dividing by 35. To this sum is added an allowance in proportion to the fulness of different bodies, determined by actual measurement.

In the Shipwrights' Repository the error of the present rule of tonnage is clearly explained, and the true tonnage is shown to be the difference between the total weight of the ship to the load-water line, and the weight of the hull and furniture. The author appears to have understood this subject, although he connects with it some erroneous observations, and has not taken the easiest method of obtaining his results. He gives several

examples of the tonnage of ships: the following is the result of his calculations on the tonnage of an eighty-gun ship: —

	Tons.	lbs.
Weight of the ship at her launching draught of water ..	1593	406
Weight of the furniture	195	720
Weight of the ship at her light-water mark	1788	1126
Weight of the ship at her load-water mark	3554	356
From which deduct the weight at light-water mark....	1788	1126
Real burden	1765	1470

	Tons.	lbs.
Burden in tons by common rule	1959	929
Real burden	1785	1470
	193	1699

The real burden of this ship is therefore 193 tons less than her computed tonnage. In an East Indiaman, his result shows that the real burden was 178 tons more than her computed tonnage. In his other examples the differences are still greater.

We shall now proceed to describe the scales of tonnage given by Mr. Parsons, and shall then conclude by some observations on the present state of the subject. Chapman, Clairbois, Atwood, and others, have calculated and drawn scales of tonnage for particular ships; but Mr. Parsons has by very considerable labour, and with great care and correctness, made the calculations and drawn the scales of tonnage, for most of the classes of ships of his Majesty's navy, and for twenty-one classes of vessels of the British mercantile navy.

The scales of tonnage are drawn for all the vessels from the keel to the gunwale: each vessel is divided into two parts, the fore and after bodies, by a vertical line at the middle of the length of the load-water line, between the fore side of the rabbet of the stem and the aft side of the rabbet of the sternpost; and a separate line of tonnage is drawn for each body. The solid content of the body in cubic feet, at different heights, is calculated by sections parallel to the keel, which being divided by 35, the number of cubic feet of sea-water in a ton, gives the weight of water which would be displaced at those heights. By

setting off from a vertical line on lines parallel to the keel these results by a scale of tons, spots are obtained, through which the line of tonnage is drawn. By setting up any height on the vertical scale of feet, and drawing a horizontal line at that height, this line represents the weight of the corresponding displacement, which is found by transferring it to a scale of tons placed horizontally over the figure. By taking the heights of the light and load-water lines of any vessel, and transferring them in this manner to the scales of tonnage, their difference gives the weight of the displacement between the light and load-water lines, or the true weight of lading. The mean depths are taken for each body separately, and the sum of the two parts thus found gives the total tonnage.

"By these lines of tonnage may be ascertained the weight put on board, or taken out of the vessel at any time, by observing the different draughts of water, and measuring the tonnage or weights corresponding to them; the difference between these weights will be the quantity put into or taken out of the vessel. For example, in the cutter of 160 tons, when ready for sea with all stores in, the[1] draught of water is 8 feet 9 inches forward, and 13 feet 6 inches aft, the mean of these is 11 feet $1\frac{1}{2}$ inches; and 12 feet $3\frac{3}{4}$ inches is the mean depth for the after body, which gives 93 tons for the weight of the after body. The mean depth for the fore body is 9 feet $11\frac{1}{4}$ inches, which gives 83 tons for the weight of that body, therefore the whole displacement is 176 tons; but the weight of the hull when launched was 82 tons, consequently the difference on the weight put on board must be 94 tons.

"This method of taking the mean depth in each body is the most correct, but will seldom be necessary; as if the mean depth of the extremities is used alone for each body, it will give nearly the same result." The tonnage is then measured by taking the mean depths of each body separately, and the difference of the results of the two methods is found to be only one ton. In vessels with a less difference of draught of water,

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[1] In this quotation the references to the scales are omitted. In Art. 14, vol. iii, of "Papers on Naval Architecture," an example is given from Mr. Parsons's previous pamphlet on this subject, in which a figure and the references are inserted.

the error is proportionally smaller. On this account the mean depths of the load and light draughts of water are used in the scales of tonnage; which "is in fact supposing the vessel to swim on an even keel, at the mean draught of water in each case."

In considering the practical benefit of the scales of tonnage, it is necessary to examine the difficulties which would attend their use. The principle of this method of measuring the tonnage of ships is strictly correct, assuming that the light and load draughts of water are determined; but in the determination of these lines appears the practical difficulty. Mr. Parsons has assumed the launching draught of water as the light draught: this is the easiest method, but not the most correct. We are considering the application of these scales of tonnage to merchant-ships; with respect to their application to the ships of the Royal navy, little need be said. The tonnage should express the lading which can be put into a ship, when every necessary article of furniture and stores is on board, to bring it down to its load draught of water. The two Swedish methods given above, one of which is in use in Sweden, removes this difficulty, by taking the light draught of water, under the necessary circumstances of having every thing on board, except the lading; an established allowance being made for every article not on board at the time. We recommend Mr. Parsons to adopt the same plan: we admit that it will be attended with considerable trouble, in obtaining the weights of the different furniture and stores; but it is the only method of obtaining the correct light draught of water, which is the first circumstance to be known in measuring a ship's tonnage. The next difficulty, and by far the greatest, is the determination of the load draught of water. Two methods suggest themselves of removing this difficulty. The load draught of water of a ship may be determined by officers appointed for this purpose immediately a ship is built, and inserted in the register, by which draught of water the tonnage may be measured. The objections to this method are, the liability of the load draught of water being incorrectly determined at first, either fraudulently or ignorantly, needing alterations afterwards; and the capability it affords the owner of taking on board, at his own

risk, a greater lading than that for which his ship was registered. Experience may, however, render the officers capable of ascertaining the load draught of water with considerable accuracy, and fines may deter the owner from incurring the risk of loading his ship deeper than it was constructed to swim with safety. Another method of obviating this difficulty, is by a ship's always paying duty on the quantity of lading on board; so that the measurement of tonnage may be taken to the actual draught of water at which the ship swims when it comes into port. This would render the load-water line at first determined little more than nominal: it would allow a vessel's being spoken of as of a nominal tonnage, which would produce no error in the measurement of the real tonnage on board. Either of the above methods may render these scales of tonnage applicable to general use; we prefer the latter, because it carries the correct principle of measuring the true lading fully into practice.

Different methods of approximation have been proposed, by taking the girths of the body, &c.; but as all these are defective in the true principle on which the tonnage can alone be correctly measured, their adoption would be attended with very little benefit. If the true principle of measuring the weight of lading be not adopted, we consider that the change of the present rule for another would be unnecessary: it would be at best but the substitution of one error for another. Methods of determining the quantity of lading have been given, in relation to the space occupied by it, without reference to its weight. The difficulties of rendering such methods generally applicable to the measurements of ships' ladings, are greater than those connected with the present method of determining the weight of the lading.

It is probable that tables of tonnage may be preferred by many to scales of tonnage; but as their principle and use would be the same, the preference is indifferent. It may also be observed, that if the whole displacement were represented by one scale, instead of being divided into two parts for the fore and after bodies, the use of these scales would be more simple in their application to the tonnage of ships, although less useful for general purposes of design.

The above observations are not intended to refer to the application of this method of measuring the lading a vessel carries, to the payment for building. A separate[1] rule for this purpose might be adopted, founded on the dimensions, scantlings, &c. of the ship. Mr. Parsons observes, that his scales of the exterior surfaces might be used for this purpose: this surface, multiplied by the mean thickness of the ship's side, would give a tolerably correct measurement of the quantity of materials. "As the expense of building vessels must be in proportion to their outside surfaces, these lines will be a much better criterion for estimating the expense than the register tonnage."

In this valuable work of Mr. Parsons, the principle on which the correct tonnage of ships depends is clearly explained, and the method of its general application shown. The whole of the scales and elements will be found generally serviceable to the naval architect in the design of ships.

Art. VI.—*A new Method of constructing Beds and Coins for Naval Guns.* By Mr. Henry Chatfield, of His Majesty's Dock-yard, Plymouth; formerly of the School of Naval Architecture.

A bed and coin being a mechanical contrivance for supporting the breech of a gun, it may be proper, before we enter into the particulars of their construction, to observe that the vertical evolutions of naval guns are confined within the limits of sixteen degrees, viz. an elevation of *nine* degrees and a depression of *seven*, when mounted on the common carriage. This being the prescribed range recently established as a guide for determining the size of ships' ports, we may regard it as a correct criterion in constructing beds and coins: but it should be understood, that when we speak of guns not being elevated more

[1] See Chapman's first rule.

than nine degrees, it is signified that that is the greatest angle at which the piece will recoil,[1] without striking the portsill.

One indispensable property which the bed and coin ought to possess, is the power of affording support to a gun at *every* point within the sixteen degrees; for unless this can be effected with certainty, the efficiency of a battery will be proportionably destroyed.

The present practice of constructing beds and coins is so defective in principle, that there is often a total absence of support to the breech of a gun sometimes to the extent of *three* degrees out of the sixteen; yet, although so obvious a defect could not fail of being frequently remarked, it does not appear that any adequate plan has been devised to correct so great an imperfection in the armament of the British navy. The interruption of support is dependent on two causes: first, The method of changing the position of the *bed* when it becomes necessary to alter its situation, in order to give more elevation to the gun than the *thinnest* part of the coin will afford; and secondly, From the coin itself not being formed on a principle of giving *continuous* support to a gun, when changed from lying flatways to being placed upon its edge. These are great and avowed deficiencies; but they have recently been modified in some measure, by supplying every gun with an additional hand-coin, similar to those used for carronades.

When a want of support occurs in actual service, so that a gun cannot be directed with precision, the coin is usually placed between the gun and the cheeks (or brackets) of the carriage to keep the breech up to its required height; but a practice of this kind is objectionable for many reasons, and can only be sanctioned as an expedient. Nothing can justify a defective system, unless it be unavoidably bad; and it is not because a naval engagement generally takes place under this or that condition, and rarely under other circumstances, that the bed and coin should be suffered to continue capable of giving partial support only to the breech of a gun. If we tolerate imperfec-

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1 Perhaps it would be better if ships' portsills were cut parallel to the *round of the beam*, or to the direction in which the gun recedes, instead of being trimmed level, or very nearly so. This would make a difference of about a degree each way, where the ship's side is of large scantling.

tions which may prevent a gun being adjusted to any *possible* elevation or depression (within the limits of sixteen degrees), we incur the responsibility of speculating with our national interests and honour, and of unfairly disappointing those who fight our battles.

Precision in naval gunnery is as important as precision in any thing else; and it will be seen by the following narrative, that where men are properly disciplined in the exercise of their guns, *theoretical inaccuracy is a practical evil;* and that the unscientific construction even of so simple a machine as a coin, may prove to be a serious defect in system, and of some moment in actual warfare.

The biographer[1] of the Hon. Captain Duncan,[2] after enumerating the many naval services of this gallant officer, observes as follows:—" There is another point which Captain Duncan has great reason to pride himself upon; namely, his attention to naval gunnery, and a recital of the circumstance which we are told first led him to see the necessity of attending thereto, may be a useful lesson to our young officers.

" A few weeks after the Porcupine (24 guns) was manned, Captain Duncan chased a ship during the night in the Archipelago, which proved to be an American merchant vessel. While hailing her, and while the two ships were almost touching each other, a gun on board the Porcupine went off by accident, and a whole broadside followed. The guns were all double-shotted, and Captain Duncan naturally supposed the neutral ship would be cut to pieces. Although happy to hear she had not suffered, his surprise was very great to find that a broadside could be fired so close without producing any effect: from that moment, he saw the absurdity of the common form of exercise which he had been accustomed to pay so much attention to as is generally done; and that real exercise, and the greatest and most constant attention to it, was necessary.

" In a short time the crew of the Porcupine became perfect gunners; the Mercury's were the same; and never, during the war, did the firing of any ship surpass that of the Imperieuse.

" One day under a battery, the captain of a gun was asked

[1] Marshall's Naval Biography.

[2] The present Storekeeper General of the Ordnance.

by an officer, why he did not fire? The man replied, The *coin edgeways is too much and not enough put flat;* I am chipping a bit of wood for it."

What could be more applicable to the subject of the present article than this anecdote? It shows the necessity of paying minute attention to what are sometimes called points of theory, but which are, in reality, broad principles in practice; and while it establishes the fact, that the support commonly given to the breech of a gun is uncertain and irregular, owing to the unscientific construction of the beds and coins, it excites one's surprise that the hint it offers has not led to the introduction of an efficient system long ago.

Before we proceed to describe the proposed method of constructing beds and coins, let us briefly consider what it is that determines the elevation and depression of naval ordnance.

The elevation of a gun at sea depends on two considerations, namely, the distance of the object to be fired at, and the lateral position of the ship.

If an object be within 400 yards, a 24-pounder gun will carry a ball to strike it when the axis of the piece is horizontal; in such a case therefore, it would be necessary to elevate or depress a gun on board a vessel, through exactly the same angle as that to which the vessel is inclined, in order to ensure horizontal firing.

This is too evident a principle to need demonstration; and it is one which may easily be acted upon by placing a pendulum (connected with a graduated arc) in conspicuous parts of a ship to denote the angle to which the vessel heels.

But if the distance of an object exceed 400 yards (the assumed point-blank range), the gun should be elevated *one* degree for about every additional three hundred yards, and the number of degrees due to the whole distance should be added to, or deducted from, the inclination of the ship, according as the enemy is to leeward or to windward.

As the *distance* of an object and the *inclined position* of the ship from which a gun is fired alone govern the vertical evolutions of a piece of ordnance, it remains to inquire whether a ship often undergoes any rapid changes of lateral position, and whether those changes are subject to a law of variation which is understood.

It is important that we should dwell a little upon this point, because the inclination of a ship is the *variable* part of the conditions of firing within point-blank range, or at a given distance, and therefore involves a most essential question in marine gunnery; and further, because it has been asserted upon high authority, that "it is not of any material importance whether the coin be adjusted or not; neither can any disappointment arise from any alteration that may take place in the position of the coin in firing."

With deference to this opinion, it is submitted that nothing can be worse than a series of guns so immethodically supported at the breech, that if the whole were discharged simultaneously, no two of them would carry a shot the same horizontal distance: or, if the rolling of the ship be made the means of giving the proper elevation of the guns, no two of them could be fired at the same instant.

When a vessel rolls through a given arc, the successive degrees are performed in unequal intervals of time, the motion not being uniform; and the action of rolling is so far analogous to the vibrations of a pendulum, that the velocity may be considered greatest in the middle of the arc, and least towards the extremities. It is obvious too, that at the extremes of oscillation, there is a temporary suspension of motion, varying in duration according to external circumstances. Now, this variation of velocity is far from being a mere theoretical difference, adduced for the sake of refining the argument or supporting a particular opinion; but it is an essential and practical alteration of velocity which is sensibly felt on board every ship, and may be as certainly calculated upon as the return of the ship to any of her former positions. This being the case, it follows that if it were intended to adjust a gun upon the plan of "watching the opportunity of firing," the most correct system would be to study those positions of the ship which afford the best means of taking a deliberate aim; and, by the same rule, to avoid that position which is accompanied with the greatest rapidity and movement.

Admitting the truth of this argument, it *is* of "material importance" how the coin is adjusted. It is material as regards the facility of firing any gun taken separately; it is also material in point of *time* (in the aggregate), a slow motion par-

taking more of the character of permanency than a comparatively quick movement; and it is material in the great object of rendering a battery uniformly and simultaneously destructive by the concurrent discharge of the artillery. There is another advantage too, in connexion with the judicious adjustment of a coin, which ought to be appreciated; and that is, the means it affords of giving the true pointing of the guns in *anticipation*, or before the object to be fired at meets the eye; which may be done without being able to see the horizon, and is as easily effected in a fog, in smoke, or in the dark, as at any other time.

It cannot for an instant be doubted, that there are many conditions under which we may encounter an adversary, when it would be a most important thing to be prepared for firing, by an approximate adjustment of the coin. In passing quickly under the stern of an enemy—in crossing his bows—in meeting him on opposite tacks—in coming up with him—in waiting his approach, &c., it is unquestionably of great consideration that no unnecessary delay take place. Now it is manifest, that if a ship be under sail (which she must be, to go through the supposed evolutions), she will be deflected from an upright position in proportion to the quantity of canvas she carries; and it is also evident, that the more sail she bears, the better will she be able to choose her situation, at the same time that she will be less liable to unsteadiness from the undulations of the sea. But the *direct* velocity of a ship requires proportional promptitude in firing, when passing an object of attack; if therefore the ship's inclination be carefully observed by an instrument on board for that purpose, it would furnish such information relative to the proper adjustment of the coin, that the utmost *precision* and *celerity* of firing would be ensured, at a moment when there may be but very little latitude for watching the roll of the ship. "It is this *instantaneous aim*," as Sir W. Congreve says, "that we are in search of for a naval sight."

Sir W. Congreve's sight is certainly a valuable invention, and will at any instant prove whether a gun is correctly pointed; but it is strange that the scientific General did not attach some importance to the adjustment of the coin, instead of trusting to the motion of the ship to give every gun, in turn, its true elevation. The intervals between the times of firing must, for

this reason, become as varied as the positions of the coins are promiscuous; and the conditions of taking aim may be favourable, or they may not; but which-ever way it may happen, it will be purely accidental. The coin should give the *level* of the gun, and the sight should give the *aim*. The coin would give the level with mathematical nicety, if the ship were quite steady; but as that cannot be the case in actual practice, it is, critically speaking, only an approximate operation to level the guns with the coins, and it therefore becomes necessary on that account to correct the deviations by the eye. Hence, "the importance of some instrument for securing the level[1] as well as the aim of naval ordnance:" and if both be made to co-operate, the art of marine gunnery will attain nearer to perfection than it possibly can so long as either consideration is neglected.

Having stated what I conceive should constitute the requisite properties of a bed and coin for naval guns, I shall recapitulate the argument by enumerating the qualities which the new beds and coins will be found to possess; and then describe the nature of their construction.

First. They will afford support to the gun at *every* point within the extreme angles of elevation and depression.

Secondly. They will regulate the *horizontal* firing, if the ship's inclination be given; and will also determine the proper pointing of a gun when the distance of an object exceeds point-blank range, provided the distance be known.

Thirdly. The *index* on the coin, and the *graduations* upon the bed, are arranged in such a manner, that it is not possible to confound the angles of elevation with those of the depression, nor to mistake one angle for another.

Fourthly. Every sailor that knows one figure from another, may work a bed and coin on this principle without any difficulty whatever.

Fifthly. None of the properties of the common bed and coin are sacrificed for the sake of the advantages proposed by the new plan.

Sixthly. That if the practice of working guns upon this

[1] Sir W. Congreve's pamphlet, p. 22, note.

"system" were disregarded, the *first* advantage enumerated would nevertheless remain unaltered, and no practical evil whatever would result from inattention to the proposed method of regulating the pointing of the guns by the inclination of the ship.

Seventhly. That every evolution can be accurately and promptly performed with *one* coin only, and only one change in the position of the bed.

Eighthly. That the whole of the elevation being obtained when the bed is in its upper position, and the whole of the depression with the bed in its lower position, the proposed plan possesses a superiority over the common system in this respect; for the average elevation of a gun when resting upon the common bed being five degrees, if the inclination of the ship vary, sometimes exceeding five degrees, and sometimes less, the bed must be shifted accordingly.[1]

Method of constructing the proposed Bed and Coin.

Fig. 13, represents a gun and carriage, with the axis of the piece horizontal. Let a level line be drawn from the lowest point of the breech, extending to Figs. 14 and 15, as shown by a dotted line. In Fig. 14, draw *a b* parallel to the dotted line, $2\frac{1}{2}$ inches[2] below it, and 3 feet long. Bisect *a b* in *c*, and draw lines perpendicular to *a b*, from the points *a*, *b*, and *c*; and let these perpendiculars be continued both upwards and downwards, as represented by *a o*, *c d* and *b f* in Fig. 14, and by the ticked lines in figures A and B.

Let the perpendicular at *b* be intersected in *f* by a level line drawn from the extreme of an arc of *nine* degrees, described through the breech of the gun from the centre *c* (Fig. 13) of the

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[1] We may easily conceive a case in point. A vessel coming up with an adversary may heel more than 5°; but if on shortening sail for the purpose of close combat, the inclination be reduced to 3 or 4°, it would be necessary to shift the whole of the beds, unless it be previously determined that no firing shall take place until the vessels are regularly engaged.

[2] $2\frac{1}{2}$ inches is an assumed dimension for the thinnest part of that portion of the coin which is intended to support the gun.

trunnion. Join *o f* (Fig. 14); then will the line *o f* represent the direction of an inclined plane capable of supporting the breech of the gun at every intermediate point from a horizontal position to nine degrees.

By construction, *o f* is bisected in *d;* if therefore *o d* and *d f* be successively introduced beneath the breech of the gun, it is manifest that the support will be perfect and *gradual* through every point within the range of 9°. This is the principle of the proposed coin.

In making *a b* equal to 36 inches, we assume a coin to be 2 feet long, which is about the common length, and that a distance of 3 inches at each extremity may be considered as over-length, thus leaving 18 inches for the *working*-length of a coin, and 36 inches for twice the working-length. Figs. A and B are each 24 inches long, and respectively show the exact form of a coin on the new principle, when lying flatways, and when placed upon its edge. The thicknesses at the extremes of the working-length of A are equal to *o a* and *c d;* and the thicknesses at the extremes of the working-length of B are respectively equal to *c d* and *b f;* consequently, after the coin ceases to raise the breech when used flatways (that is, with the depth *c d*), it will, when turned upon its edge, commence to give support at the same depth or angle, and continue to do so through the remaining degrees to the depth *b f*, supposing it to traverse upon a horizontal bed.

Again, it is evident that if the gun were supported horizontally upon the point *f*, the point *f* being brought to a level with the breech by *lowering the bed* sufficiently for that purpose, the breech would descend through 9° with the same regularity that it was before raised, provided the coin be *withdrawn* first on its edge and then flatways. Hence the same coin may be made to answer for the whole of the elevation, and the whole of the depression, if the bed upon which it is worked be properly adjusted for the distinct cases.

Figs. 16 and 18 represent the upper and lower sides of the bed, with the degrees marked thereon, to show the angles of elevation and depression. There is an index both on the side and edge of the coin, at one common point, so that while one is exposed the other is, of necessity, concealed; and *vice versa.*

These indices traverse across the graduations, and always point out the exact degree to which the gun is elevated.

A pair of side-chocks (or legs) as shown by a side-view Figs. 13 and 17, an end-view Fig. 15, and a horizontal view, Figs. 16 and 18, are securely attached to the bed by two bolts; and the bed is made just wide enough at this place to admit of the broadest part of the coin passing between them when traversing upon the bed in its reversed position.

It has previously been observed that the extreme elevation of naval guns is 9°, but that the depression is limited to 7°, therefore, at the point where the inclined line $o f$ (Fig. 14) will depress the gun 2°, draw $x y$ vertically. Apply $x y$ in a vertical direction below the breech of the gun (Fig. 13); this will give a point in the upper part of a bed, which, being fixed horizontally, will allow a coin formed from the moulds A and B to support a gun horizontally upon the point x, and subsequently to depress it through every point extending to an angle of 7°. This is done to keep the bed as low as possible, which is desirable for several reasons, viz. it shortens the side-chocks (or legs), which are thereby rendered less liable to injury; it reduces the weight of the bed; it lessens the expense; and it furnishes a better bearing for the coin, as seen in Fig. 13, than if only the overlength (or tip) of the coin were under the breech when the gun is at point blank.

The legs are intended to stand upon a thin chock placed on the upper part of the axle tree. This chock will be a "regulation chock," varying in thickness according to the round of the beam at the several ports; and is introduced with a view to prevent any alterations in the beds after they are once made, thereby rendering any sets of beds always applicable to the same description of gun, and indiscriminately answerable to any port in a ship. The length of the side-chocks should be equal to the *sine* of 7°; or, equal to $f b - x y$ (Fig. 14).

When the bed is in its upper position, it is, as before stated, the distance $x y$ (Fig. 14) $=$ *sine* $2° + 2\frac{1}{2}$ *inches*, below the breech of the gun; but when it is in its lower position, it is the distance $x y +$ *sine of* $7° = 2\frac{1}{2}$ *inches* $+$ *sine* $9° = f b$ (Fig 14) below the breech: and it is thrown into this last position by *reversing* the bed and placing its inner end upon an

extra bed-bolt fitted to receive it. The bed is seen in a reversed position in Fig. 17, where *f* is the supposed point of horizontal support, from which the whole of the elevation is given, by withdrawing the coin successively on its edge and side.

The plan of giving the whole of the elevation with the bed in one position, and the whole of the depression with the bed in another position, is novel, and is less liable to mistake than when it is necessary to shift the bed while a ship is on the same tack, in consequence of a variation of inclination.

The method of obtaining the scales of graduation upon the beds may be very well understood, without letters of reference, by inspecting figures 19 and 20, where the axis of the piece, the trunnion of the gun, the diameter of the breech, and the arcs described by the breech by introducing the coin successively on its side and edge, are shown. The degrees of the arcs are levelled over to the inclined lines representing the upper part of the coin in its two positions, and those points are then squared down to the base of the coin. In this manner we arrive at the horizontal distances through which the coin must traverse under all the varieties of elevation and depression; and this is all that need be done in actual practice in addition to what has been explained, with the exception of placing the *bed-bolts*.

To find the positions of the bed-bolts. Place the gun-carriage as nearly as possible in a situation similar to that in which it will stand when upon the deck; in other words, make an allowance for the round of the deck, in the distance between the fore and hinder trucks. An average of half an inch in a foot will be found to answer very well.

Draw a vertical line on the cheek of the carriage, passing through the centre of the trunnion of the gun, and upon this line set off a distance below the *axis* of the piece, equal to the *radius of breech* + $x\,y$ + *thickness of the bed*, and then draw a horizontal line through this point along the bracket of the carriage.

From the vertical line, set off, on the line last drawn, the length of that portion of the gun between the centre of the trunnion and the breech; this will give a point vertically below the breech when the gun is level. Set back 21 inches, that

being the extreme distance that the coin will ever pass under the gun, viz. 18 inches working-length, and 3 inches over-length, and make this point the position of the upper bolt *m*, Fig. 13. It will represent the under part of the bolt, admitting that the bolt has sunk its diameter into the score in the bed.

The lower bolt *p*, Fig. 13, will be as much below the upper one as the *length* of the side-chocks below the under part of the bed; consequently the bed, when reversed, will be parallel to its former position. Draw therefore another horizontal line upon the bracket of the carriage, and place the bed-bolt anywhere upon this line, so that it will afford a good bearing when the bed comes to rest upon it, and that the score upon the upper surface for the bed-bolt be situated between the graduations marked upon the top of the bed.

This explains the greatest difficulty that attaches to the plan, but it is one which was thought very little of by intelligent mechanics with whom I have had intercourse at the gun-wharfs on this service.

Every coin should be (like some recently fitted at Portsmouth) plated upon two of its surfaces from end to end, with a thin iron bar, about $1\frac{1}{4}$ inch broad, and $\frac{3}{16}$ of an inch thick (let in flush with the wood), to prevent the breech of the gun indenting the coin, which is an excellent preventive against one of the inaccuracies in practice often injurious to theory.

There is another casualty which ought to be guarded against, as affecting the height of the breech relatively to the trunnion, and which therefore alters the angle of elevation; it is the *shrinkage* of the trucks, especially the hinder ones, which, as they become seasoned, assume an elliptical form, owing to the contraction of wood being greater across the grain than in the direction of the fibre. This is by no means an unimportant consideration, though it may easily be rectified by making the trucks of two thicknesses (placing the grain of the wood crosswise), or by making them of timber less liable to alteration of form from atmospheric influence. We cannot attend too particularly to points like these, for the height of a ship's hull is not sufficient to justify the slightest disregard to contingencies which affect the vertical evolutions. Sir William Congreve has very justly said, " I do not hesitate to assert that

without some well-organized instrument for pointing guns on board ship, with any motion in the vessel, there can be no certainty of practice even at 200 yards distance."

After the authorities that have been quoted, it cannot surely be questioned whether a gun ought to be supported with accuracy at every intermediate point between the limits of elevation and depression; nor can it be thought a too great refinement of principle, to insist on the advantages of an organized instrument for regulating the level of guns at sea, *methodically*, lest we should miss the hull of a ship even at 200 yards distance.

In conclusion. A model of a bed and coin constructed in the manner already described, and possessing the properties which it has been contended a bed and coin ought to possess, was first made in June last. It was shown to a few naval officers, who expressed themselves much pleased with the plan; and in the course of the following month, it was submitted to the Hon. Captain Duncan, at the Ordnance.[1]

Nothing could be more gratifying than the liberality with which the proposition was received, and the facilities at all times afforded in every branch of the Ordnance Department.

Fourteen beds and coins were shortly afterwards fitted for trial on board his Majesty's ships Caledonia, Isis, Magicienne, and Pylades; and others would have been put on board the Asia and Revenge, if they could have been finished in time; but these ships, then lying at Spithead, were unexpectedly ordered to sea. Four sets of beds and coins were ordered for every ship excepting the Pylades, and she of course had them to her two bow guns only.

The opportunities now afforded for making experiments will soon determine whether the proposed beds and coins are superior to those at present used in the navy. If they should be found imperfect, the fault will be in the *detail;* for the principle is as demonstrable as any proposition in Euclid's elements.

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1 Captain Blankley (commander of the Pylades) was one of the first who examined the model, and I am indebted to him for the honour of an introduction to Captain Duncan, and for having immediately applied for beds and coins on the principle recommended.

Art. VII.—*On the Protection of Ships from Lightning.* By W. Snow Harris, Esq., F.R.S.—(Continued from page 446 of vol. III.)

33. Having in some preceding observations pointed out the necessity of guarding the British navy against the operation of natural electricity, and entered upon the theory of lightning-rods generally, we have now to consider the most effectual methods of their application in ships; so as to obtain as complete protection in thunder-storms as can be reasonably expected from the advances yet made in natural knowledge.

34. It has been already observed (16), that in every case of damage from lightning, the electric matter is determined between the points of action through such line or lines, as, upon the whole, oppose to its progress the least comparative resistance; upon which simple and well-determined fact it is that we are enabled to derive protection in thunder-storms. It must be here remembered (11), that the materials of which ships and buildings are constructed, are themselves conductors of electricity, and are capable, alone, of transmitting, in a variety of instances, considerable quantities of natural electricity, (22). It may therefore be reasonably inferred, that, by completing a perfectly continuous and efficient line of metal from their most elevated points to the base on which they happen to be placed, the damage which so frequently occurs might be either greatly palliated or altogether avoided.

35. The application, therefore, of a lightning conductor, to a building or ship, must be always considered as a means of rendering more efficient the conducting power of the whole mass, so as to transmit such intense discharges of atmospheric electricity, as could not otherwise pass without intermediate explosion and damage. Thus, whilst the mast and rigging of a ship derive a direct protection from the metallic substance attached to it, the latter, in its turn, is relieved from as much of the action as the former is capable of transmitting. The following electrical experiments, which are new of their kind, will serve to illustrate this important fact.

(*a*) Let a fine wire of iron, about the $\frac{1}{200}$th of an inch in

diameter, and about twelve inches in length, be stretched perpendicularly between two insulated points, and let such a charge of artificial electricity be accumulated, and transmitted through this wire, as will *just* fuse it, but not more. Let a similar length of wire from the same reel be now closely applied to a cylindrical piece of rather damp wood, and placed between the same points as before. If a similar accumulation be now discharged upon the wire, the wire will remain perfect; the transmitting power of the damp wood being sufficient to protect it from that particular accumulation.[1]

(β) Let a similar wire to the preceding be caused to pass through the centre of a finely-exhausted receiver, it will now be extremely difficult to fuse it by any ordinary charge which we can accumulate; the little resistance offered by the vacuum to the superabundant quantity of electric matter being sufficient to prevent it from passing through the metal. It is, in fact, on the principle above stated (16), less difficult for the electric matter to pass through the vacuum than through the wire, at the point of fusion. I have known an extremely fine iron wire treated in this way, which remained perfect, under an explosion from twenty square feet of coated glass, highly charged, whilst in air it became fused by the charge of a small jar.

(γ) Let a model of a mast of about six feet in height be constructed, in two vertical parts, having an interrupted line of metallic wire passed through its centre longitudinally, so as to insert, between the opposed points of the wire, which may be about one-fourth of an inch apart, or more, a quantity of percussion-powder, and let such a charge be accumulated as will pass freely over these interruptions; the powder between the points will, on passing the charge through the mast, become exploded, and the parts of the mast thrown asunder. Let the whole be again replaced as before, and an extremely fine wire, or slip of gold-leaf, attached to the mast. In this case an accumulation may be discharged upon the whole, nearly equal to the fusion of the wire, before any portion of the charge will pass inside in the

1 This is a somewhat delicate experiment, and requires a very careful adjustment of the accumulation by which the wire is to be fused. For an accurate method of effecting this, see Transactions of the Plymouth Institution, vol. i. p. 94. See 44.

interrupted circuit, and force the parts asunder; so that, with the same accumulation as before, the mast will remain perfect. If the intervals between the wire inside the mast be sufficiently great, then the protecting wire may even undergo complete fusion, without the powder inside becoming exploded.

36. Since damage in thunder-storms only occurs when the electric matter cannot be transmitted with sufficient rapidity, as in the cases above cited (n) (o) (22), it may be hence fairly inferred, that although we should never come to know the actual quantity of electric matter liable to be discharged in a thunder-storm, we have, nevertheless, by increasing the conducting power of the mass, multiplied the chances of escape in an extraordinary degree. Mr. Cavendish has proved, that even the conducting power of water is a million times less than that of iron wire.[1] It appears from a notice given by Mr. Cavendish, of some experiments he has made on this subject, that iron wire conducts about four hundred million times better than distilled water.

37. Although the application of lightning-conductors to buildings on shore is always judicious, and the resulting advantages fully apparent, yet on ship-board, where the effects of lightning are still more to be dreaded, the introduction of this means of defence has been slow and imperfect. On shore, stationary elevations may be defended by means of rigid metallic rods, which may be either perpendicular, or carried over projecting portions of the edifice, without impairing their efficacy. On ship-board, however, the case is widely different. The masts, though erect, consist of many distinct portions; these it is often necessary to move one upon another, and sometimes to remove altogether; they are also liable to damage from wind and other accidents; whilst the quantity of cordage and canvas, so constantly about the masts, often necessarily renders the condition of a lightning-conductor still more complicated. With a view of meeting these difficulties, the conductors employed at sea usually consist of long links of metal, or chains, about the size of a goose-quill, forming a semi-flexible metallic line; they are sometimes made of iron. Those

[1] Transactions of the Royal Society.

employed in his Majesty's navy, however, are of copper; they are attached to a hemp cord, and being packed in a box, are intended to be set up from the mast-head when occasion requires; so that, as observed by Mr. Singer, in his excellent work on electricity, partly from inattention and partly from prejudice, they frequently remain unemployed in the ship's hold during long and hazardous voyages; a remark the truth of which is but too frequently verified, in the damage which so frequently occurs at sea in severe storms of lightning.[1] (n) (o)

38. These conducting chains above mentioned, beside being uncertain in their application, are, in a variety of instances, but ill-adapted to the circumstances under which they are to be placed; inasmuch as they are open to every sort of external violence incident to a ship's rigging, and are very liable to be deranged in their situation, more especially in gales of wind, at night, when the ship is under sail; and when, perhaps, it is required to remove the higher portions of the masts altogether. They must, therefore, be considered only as inconvenient substitutes for fixed and more extensive masses of metal, of uninterrupted continuity, the great want of which, in every kind of chain, is extremely unfavourable to the free transmission of large quantities of electricity, whilst the electric matter, in becoming sensible at the points of junction, frequently disunites the chain at each link by its expansive force (o).

39. The above considerations, together with the damage which so frequently occurs to ships in thunder-storms, are alone sufficient inducements for attempting the application of such permanent conductors on ship-board as may at all times be competent to afford security, which may be always in place, and always ready to meet the most unexpected danger, without being in the least degree dependent on the exertions of the crew.

40. In order to effect this, it becomes essential to complete the conducting power of the masts themselves, up to the greatest possible extent consistent with convenience in practice, seeing

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[1] A minute account of the case of damage by lightning, on board the New York Packet, may be seen in the Liverpool Chronicle, May 1827, from which it appears, that the conducting chain, at the time of the first explosion (n), was carefully stowed away in its box in the ship's hold, although set up in time to avert the effects of the subsequent explosion (o).

(11) that the masts are already so circumstanced that the course of a stroke of lightning is actually determined by their necessary position, immediately through the body of the vessel, and which is the more exposed on that account to damage, if the conducting power of the masts remains low and unassisted. It will be therefore requisite to identify with the masts, a continuous line of metal from the vane-spindle at the mast-head to the sea.

41. For this purpose a sort of double conductor, of a superficial kind, consisting of two separate laminæ of metal, placed one on the other, may be easily formed of sheet copper, in short lengths of about four feet; the two laminæ may be so united as to cause the butts or points of the one layer to fall immediately under the continuous portions of the other. The width of this conductor may vary from an inch and a half to six inches, according to the size of the mast, the whole thickness being about 3-16ths of an inch. The lengths must be first secured by means of rivets, at the points of junction, so as to form a perfectly continuous and elastic line of metal; this is to be inserted under the edge of a neat dove-tailed groove, ploughed longitudinally, in the aft sides of the masts, where it is subsequently secured by means of wrought copper nails, so as to have a fair surface; the nails are driven at each side, about four inches apart. The groove, previously to applying the metal, should be freely painted over with white lead, and must be sufficiently deep to allow of the copper being somewhat below the surface of the wood.

42. The metallic line thus formed will then pass from the vane-spindle, or extremity of the mast, along the aft sides of the royal mast and top-gallant mast, being connected in its course with the copper about the sheave-holes. A copper lining in the aft side of the hole in the cap through which the top-gallant mast slides, may now carry on the connexion, and continue it over the cap to the aft side of the topmast, and so on to the step of the mast; here a wide copper band is to be turned round the step under the heel of the mast, resting on a similar band of copper, which traverses the keelson longitudinally, connecting together for eight or ten feet on each side of the step all the keelson bolts; these bolts should have

a perfect and good contact with the copper inserted between the keel and false keel externally. In lieu of these bolts the copper band on the keelson may be connected with three or four perpendicular bolts of copper, varying from one to two inches in diameter, which may be driven, expressly for the purpose, into the main keel, upon as many transverse or horizontal bolts brought into immediate contact with the copper expanded on the bottom.[1] The laminæ of copper are to be turned over the respective mast-heads, and completely round the heel of the mast, being secured on the opposite sides for about an inch or more in length. The copper connexions in the caps are to be prepared in a similar way, each of them being continued from the lining in the aft side of the round hole, over the cap into the fore part of the square one, where the metallic band is turned over and secured as before, so that when the cap is in its place the contact is complete.

43. Beside the connexions with the keelson bolts, wide conducting bands, formed as before, should be led out on each side transversely, from under the beams nearest the masts, immediately to the iron knees or other metallic fastenings in the sides. In this way all the detached masses of metal of consequence in the hull will be completely connected with the conductors on the masts, through the intervention of the copper expanded on the bottom—a condition of the utmost consequence, as the action of the conductors is, in fact, nothing more than a rapid diffusion and equalization of the electric action, by which the concentrated and dense explosion is avoided.

44. The conductors under the beams are connected with those on the mast, by means of a sliding bolt, or otherwise by the intervention of copper plates inserted in a simple and ingenious manner between the mast and beams, so as to ensure a perfect contact, as suggested by Mr. Rice, of his Majesty's dock-yard at Chatham.

45. A lightning-conductor thus applied to the mast of a ship, adds considerable strength to the mast itself, of which it is made

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[1] When the mizen-mast does not step on the keelson, metallic connexions must be continued to the keelson bolts and other metallic fastenings, immediately from the termination of the conductor in the step, in any way most convenient.

to form a portion,[1] and is capable of resisting any external force; whilst, by presenting a fair surface, it admits of the parrel of a yard traversing the mast with ease; and being secured in short lengths, so as to form a series of close joints, will readily accommodate itself to any curve which the mast can stand under. A very perfect continuity is also maintained under all the varying positions of the masts, and there is a sufficient quantity of metal to ensure a very rapid transmission of the electric matter; it has, besides this, the capital advantage of being applied immediately to the object to be defended. (Exp. α.)

In the operation of such a conductor, it is further evident, that whatever position we suppose the sliding masts to assume, whether partially struck or otherwise, still there is a perfectly continuous line of conduction to the sea, since that portion of the conductor which remains below the caps and tops when the higher masts are struck, or partially so, is no longer in the line of action, it has consequently no longer any influence in the operation of transmitting the electric matter.

46. The conducting power of metallic bodies appears to vary considerably, although for very low electrical actions they may be considered as equal; the differences, however, become greater in proportion to the extent of the charge to be transmitted. Copper has, in all intense actions, a decided superiority over every other metal except silver, it is therefore, on this account alone, well adapted for the purpose of a lightning-conductor; besides which, it is very manageable: compared with iron, a metal frequently employed in the construction of conductors, it was found in some particular instances to resist the heating effect of a given charge in the ratio

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[1] The result of an extensive series of experiments, carried on in his Majesty's dock-yard at Portsmouth, showed that a flexible spar with the attached conductor, required a mean force of 48 lbs. upon 5 cwt., in order to bring it to the same point of flexure as when the conductor was not present—the spar being submitted to experiment on its eight squares; whilst in some positions it required upwards of 100 lbs to deflect it to the same point, that is, nearly 1·5th of the above weight. Now, although we cannot say, that the more flexible the spar the sooner it will break, yet it may be reasonably inferred, that in the *same* spar, any-thing which tends to give it greater stability, and prevent it from reaching under a given force, that point of flexure at which it may be supposed to fracture must necessarily add to it strength.

of 5 to 1.[1] Dr. Priestley has also observed, that the force required to fuse a wire of copper of a given diameter, would most probably dissipate an iron wire of *twice* that same diameter.[2] Mr. Singer also observes, that when a conductor is wholly of copper, it may be thinner than if made of iron.[3]

47. The following Table shows the extent of a conductor on the proposed plan (41), on one mast of a frigate of 50 guns as compared with the copper links usually employed in the British navy, together with the necessary equivalent in copper or iron bolt, in order to obtain a conductor of the same value. It has been calculated on the supposition that the two laminæ of copper forming the conductor are 1-8th and 1-16th of an inch in thickness respectively throughout.

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[1] Hist. of Electricity, p. 638. [2] Singer's Electricity, p. 226.
[3] See "Transactions of the Royal Society" for the year 1827, p. 22.

TABLE

SUCCESSION of MASTS.	1 Proposed Conductors.		2 Equivalent in a Copper Rod.		3 Equivalents in an Iron Rod, taking Conducting Powers only as four to one.			4 Mass and Surface in a Copper Rod of half-inch diameter.		5 Mass and Surface in present Conductors.	
	Mass.	Surface.	Diameter.	Surface.	Mass.	Surface.	Diameter.	Mass.	Surface.	Mass.	Surface.
	Cubic inches.	Square inches.	Inches.	Square inches.	Cubic inches.	Square inches.	Inches.	Cubic inches.	Square inches.	Cubic inches.	Square inches.
ROYAL POLE CONDUCTOR. Copper plates; 18 feet 3 inches long, 2 inches mean width	92	1752	·69	474	328	949	1·38	42	343	10·5	171
TOP-GAL.-MAST CONDUCTOR. 17 feet long .... 2½ inches wide	95	2040	·77	493	380	986	1·54	40	320	10	160
TOPMAST CONDUCTOR. 50 feet long and ...... 4 inches wide	450	9600	·97	1463	1800	2926	1·95	117	942	19·2	471
LOWER-MAST CONDUCTOR. 93 feet long and....... 6 inches wide	1255	26784	1·20	4212	5020	8421	2·20	219	1753	54·7	876
Total	1882	40176	1·058	7119	7528	14238	2·116	418	3358	94·4	1678

The resulting quantities in the *last* line at the bottom of the table represent, with the exception of the new conductors, the masses, surfaces, and diameters, of cylindrical metallic rods, supposed to extend the whole length of the mast. Thus, in column 2, we have the diameter and surface of a copper rod containing 1882 cubic inches of metal, being an equal quantity of matter to that in the new conductors, and the sums therefore are not the result of the addition of the successive masts. The same may be observed in column 3, taking the equivalent in iron. In the fourth column we have the mass and surface of a copper rod of half an inch in diameter, generally considered as adequate to transmit any stroke of lightning as yet experienced; and, lastly, in column 5 we have the mass and surface in the conductors now furnished to the British navy.

48. The objections which have been urged to the conductors above-mentioned are, for the most part, such as have been already combated in the preceding pages (19), and therefore require but little further consideration. It has been said, however, in addition, that since we can never come to know the extent of every possible discharge of atmospheric electricity, the superficial conductors may become fused;—that in fixing conductors in the masts we can only have surface, whereas a dense mass of metal is requisite, if we wish to prevent fusion; hence the metallic surfaces are calculated to bring destruction on the vessel;—that the conductors are objectionable, in consequence of their passing immediately through the body of the vessel, and consequently near the magazines; and lastly, that in a mechanical point of view, the plates of copper are not likely to stand the pressure of sail and working of the masts. We shall, as before, proceed briefly to consider those additional objections, which, it must be admitted, are in themselves very reasonable matters of discussion, and very fairly urged.

49. The notion that a ship can possibly be in a worse condition *with* than *without* the conductor, has been already shown (24) to be an erroneous one. Indeed, the reverse of it appears to nearer the truth (36), since, as has been just stated, although we *should never know* the actual quantity of electric matter which may possibly be discharged in a thunder-storm,

we have, nevertheless, by completing the conducting power of the masts, greatly multiplied the chances of escape.

50. With respect to the absolute fusion of the conductors, it may be laid down as an axiom, that a given quantity of metal can always transmit any electrical accumulation equivalent to its fusion; this is evident, since the fusion arises from the electric matter actually transmitted. Now, on a review of the various cases of damage by lightning, it cannot be said that a conductor equal to a copper rod of 1,058 inches diameter, and 210 feet in length, which may be taken as the mean value of the conductor on one mast of a frigate of 50 guns, is at all likely to be fused. In short, the evidence we possess from actual experience (28) is conclusive against such an opinion, and goes far to prove, that little short of an atmospheric explosion from electrical action, capable of involving the ship and everything on board in one common ruin, could dissipate so great an extent of metal. Such unheard-of and unknown convulsions we pretend not, as already observed (28), to have any power of withstanding.

In the foregoing considerations we have only taken into account the action of a single mast; but it is fair to presume, that the conductors on each mast would be brought into action before any single one could undergo fusion, in illustration of which I shall cite the following experiments.

(δ) Let a single and very fine wire of iron be stretched in a perpendicular direction between two horizontal insulators, and immediately under a larger conducting ball, from which an explosion may be caused to pass, just sufficient to fuse the wire. If a second wire, stretched in a similar way, be now added, and placed near the first, so as to be equi-distant from the large conducting ball, the explosion will break upon the two, but neither will be fused. Let now an accumulation be obtained capable of fusing both the wires. Then, if three wires be placed under the conductors, the explosion will divide upon the three, and neither will be fused. The discharge is here supposed to pass upon spheres, between which the wires are secured; but if a pointed termination be given to the spheres, then the single wire will be no longer fused with the same extent of charge. We may hence infer, that previously to either

of the conductors being fused, the others would be brought into action (16), and that hence we may fairly calculate on the fusion of all or none.

51. If, therefore, we add to the great capacity of the conductors in question their conjoint action, and the very favourable conditions under which they are placed, that is to say, their pointed terminations above, and their perfectly uninsulated state below, we have every reason to repose confidence in their efficiency. So that, instead of the disastrous results arising to ships from atmospheric electricity, we should find the electric matter rapidly dissipated, and transmitted, in a state of such low tension, to the sea; that, in a great variety of cases, no explosion would be found to occur. Indeed, such seems to have been actually the case in his Majesty's frigate Dryad, now on the coast of Africa, under the command of Commodore Hayes, and one of the few ships in the British navy equipped with lightning-conductors on the plan above detailed. I learn, from my friend Captain Turner, of the above ship, whose intelligence, in everything connected with his profession, is only exceeded by his anxiety to promote its interests. That after having experienced some severe lightning on the coast, they encountered a tornado, during which both the fore-mast and mizen-mast were assailed at different times by heavy discharges of lightning. The electric matter fell on the conductors so freely, that in passing them, it produced a sort of luminous atmosphere, and escaped through the hull with a noise resembling the violent boiling of water; a result, he says, which has given all on on board the greatest confidence in the efficiency of lightning-protectors, when properly applied.[1]

52. It is a mistake to suppose that the conductors thus superficially applied to the masts, are without considerable powers, when considered even in relation to their thickness, as may be seen by reference to the Table above given (45); moreover, admitting that quantity of metal *is* the great desideratum in a conductor, still it must be equally efficient in any form: for the conducting power of the mass must consist

[1] I have every reason to believe that an express communication on this subject was sent to the Lords Commissioners of the Admiralty, by Commodore Hayes.

of the conducting power of all the parts of that mass. Now it would be absurd to suppose that a mass of metal, expanded into any extent of surface, does not still conduct in all its parts; indeed, our experience of the effect of electricity on metals is quite conclusive in this question, since it is impossible to destroy a portion of a perfectly homogeneous metallic surface, of uniform density and thickness, by an artificial accumulation of electricity, without destroying the whole. We do not take into the account here any immediate edge or single point upon which the discharge is first concentrated.

53. It would seem, from the fine and conclusive experiments of Sir H. Davy,[1] that a considerable advantage is obtained, by expanding a mass of metal into an extensive surface; since, by so doing, we expose it to a greater extent of cool air, by which its temperature is kept low, and the heat caused by the discharge much diminished. That the conducting power of metal is greatly impaired by increase of temperature, is a fact beyond a question; the very few experiments adduced to the contrary are altogether inconclusive. A given quantity of metal, therefore, formed into a hollow tube, might possibly withstand an intense discharge; whilst in the form of a solid rod it would become fused.

54. The circumstance of the conductors passing through the ship is not an objection of any moment, more especially, as already so often insisted on, when we take into account the situation of the masts themselves, which, in almost every instance, determine the course of the electric matter in that direction. Moreover, we invariably find, as is well observed in the "Transactions of the Royal Society," that in most cases of lightning on ship-board, no mischief occurs after the lightning reaches the well. That the electric matter may be safely carried through the ship to the sea, is very evident from experience; it is, in fact, owing to the metallic fastenings, which admit of this operation going on, that most of the ships struck by lightning are saved from extensive damage in the hull. We find such to be more peculiarly the case in his Majesty's ships, where metallic fastenings are in abundance; and which, being

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[1] Transactions of the Royal Society.

all actually, or very nearly connected with each other, by means of the copper expanded on the bottom, cause the electric action to be rapidly equalized in the vessel and surrounding water: it is, indeed, not a little remarkable, that the more serious cases of damage in the hull have occurred in merchant vessels, where metallic fastenings have been little prevalent. In further illustration of this important fact, we may cite the case of his Majesty's ship London, in which the fore-mast was shivered to the keel, whilst the kelson, step, and keel, remained perfect.

55. That the conductors pass *near* the magazines is allowed; but such is the case, to a great degree, in all magazines defended by lightning-conductors; they are necessarily placed near them for their protection; for we well know that the electric matter will not leave a *good conductor in the line of action* to pass upon detached or less perfect conductors out of that line (Exp. 7, s. 35). We may therefore certainly infer, that whenever the lightning is fairly led to the conductor in the hull, the danger is over. Without the conductors, damage in the way above-mentioned is by no means unlikely. Thus, in some vessels, there is not unfrequently an iron spindle, upon which the capstan is supported, immediately over the after-magazine. This would inevitably transmit the electric matter to the point in which the spindle terminates, from which it would fly off in a dense and concentrated form, to the next point which happened to lie in the line of action. The same reasoning applies to the masts, which, if not exclusively made the line of action, would admit of the electric matter being transmitted through such other points as might, upon the whole, be found to oppose to its progress the least resistance.

56. The mechanical application to the masts is an objection of a more palpable kind, and can be only met by experience: with the exception of a few trifling instances, in one or two ships already fitted, little defect has occurred. In the Dryad, above-mentioned (49), no complaint whatever is made—rather on the contrary. The copper is stated to stand extremely well on the masts, notwithstanding that the masts have been frequently exposed to a heavy press of sail in chase, and likewise to very severe weather. Now it must be remembered, that this ship has passed from a cold to a burning climate. It would, how-

ever, be surprising, if the infancy of any contrivance were to be equally perfect with its more advanced state, or that every difficulty possible to occur in practice could be at once foreseen and provided against. From the circumstance of the conductor being constructed in many parts, there appears every reasonable ground for believing, that when perfectly applied on the masts, the copper will withstand any action which it may be fairly liable to, consistent with the safety of the mast itself. In the experiments above alluded to (45), a spar, with the attached conductor, was repeatedly submitted to an extreme flexure by weights, without at all deranging the copper, which seemed to play freely with the bending of the spar; on the weights being withdrawn, the whole returned to the previous line of direction, to within the 1-50th part of an inch, as measured by an index placed on the axis of a small wheel delicately hung, and which carried a fine silk line and counterpoise attached to the centre of the spar; the elasticity of the whole therefore seemed very perfect.

57. If I have been at all successful in the preceding observations on the protection of ships from lightning, we may venture to affirm, that the proposed method of defence is efficient and practicable, and if carried generally into effect, is likely to be productive of very beneficial consequences to shipping generally; besides that, it must be satisfactory to know, that we have availed ourselves of the means which science has so long suggested, and which experience has confirmed, of avoiding the fatal consequences resulting to ships from strokes of lightning. In the present state of the question, these means may be considered as either ineffectually applied, in the greater number of instances, or otherwise totally neglected. It must be considered as matter of regret, that a discovery considered by scientific persons as one of the most important yet arrived at by electrical inquiries, and offering the greatest practical advantages, should, for so long a time, have been unproductive of all the benefits of which it is susceptible; for although buildings on shore have, for a long period, been effectually protected, by means of lightning-rods, against the danger arising from atmospheric electricity, yet it must be admitted that, during

the same lapse of time, ships have been constantly suffering from this source of danger.

58. Although this subject has not been properly appreciated by many persons, under an impression that the chances of damage from lightning are too few and inconsiderable to warrant even the little trouble and expense necessary to avoid them; yet I trust to have made it appear that such opinions are by no means founded on reflection, and that a judicious application of fixed and continuous lightning-protectors, on shipboard, is not only desirable for shipping generally, but is in a great variety of instances absolutely essential to their preservation.

Plymouth, Dec. 14, 1831.

Art. VIII.—*A List of Patents which have been taken out since the* 1*st of July* 1831 *for Inventions or Improvements connected with Naval Affairs; with Extracts from Specifications, &c.*

To Thomas Westrup and William Gibbins, both of Bromley, in the county of Middlesex, gents., for improvements in converting salt or other water into pure or other water. Dated May 24th, 1831.

To Jacob Perkins, of Fleet-street, in the city of London, engineer, for improvements in generating steam. Dated July 2d, 1831.

To Baron Charles Wetterstedt, of Whitechapel-road, in the county of Middlesex, for a composition or combination of materials for sheathing, painting, or preserving ships' bottoms, and for other purposes. Dated July 6th, 1831.

To Moses Poole, of Lincoln's-inn, in the county of Middlesex, gent., for certain improvements in steam-engines, and in propelling boats and other floating bodies, parts of which im-

provements are applicable to other purposes. Communicated by a foreigner. Dated July 13th, 1831.

To Augustus Demondiou, of Old Fish-street-hill, in the city of London, for certain improvements on guns, muskets, and other fire-arms, and in cartridges to be used therewith, and method of priming the same; and in the machinery for making the said guns, muskets, and fire-arms; also the cartridges and priming; which improvements are also applicable to other purposes. Communicated by a foreigner. Dated July 13th, 1831.

To William Batten, of Rochester, in the county of Kent, gent., for an apparatus for checking or stopping chain-cables; which apparatus may be applied to other purposes. Dated 13th July, 1831.

To John de Burgh, Marquis of Clanricarde, for certain improvements in fire-arms, and in the projectiles to be used therewith. Communicated by a foreigner. Dated July 15th, 1831.

To Sir James Caleb Anderson, of Buttevant-castle, in the county of Cork, Ireland, baronet, for certain improved machinery for propelling vessels on water, which machinery is applicable to other useful purposes. Dated August 2d, 1831.

To George Holworthy Palmer, of Manchester-street, Grays-inn-road, civil engineer, for certain improvements in the steam-engine, boiler, and apparatus, or machinery connected therewith, applicable to propelling vessels, carriages, and other purposes. Dated September 16th, 1831.

To Mark Cosnahan, of the Isle of Man, esquire, for certain improvements in apparatus, modes, or process, for converting sea or salt water, and also other brackish, turbid, or impure waters, into purified or fresh water; which apparatus, modes, or processes, or parts thereof, may be applied to other purposes. Dated September 20th, 1831.

To William Bingham, of St. Mary Hall, esquire, and William Dupe, gun-maker, both of Oxford, for certain improvements on fire-arms of different descriptions. Dated September 24th, 1831.

To Henry Hope Werninck, of North-terrace, Camberwell, in the county of Surrey, gent., for certain improvements in

apparatus or methods for preserving lives of persons and property when in danger by shipwreck, by speedily converting boats or small vessels of ordinary description into life-boats, and other apparatus or means applicable to the same objects. Communicated by a foreigner. Dated September 24th, 1831.

To Oliver St. George, of Great Cumberland-street, in the county of Middlesex, esquire, for certain improvements in machinery for acquiring power in tides or currents. Communicated by a foreigner. Dated September 28th, 1831.

To Miles Berry, of the Office for Patents, 66, Chancery-lane, in the parish of St. Andrew, Holborn, in the county of Middlesex, Engineer and Mechanical Draftsman, communicated by M. Jean Nicholas Senéchal, *Ingenieur des Ponts et Chassees*, residing at Versailles, in France, for certain improvements in the boilers or generators of steam or other vapour, and in engines to be worked by steam or vapour, for propelling or actuating machinery on land, and vessels or other floating bodies on water; and also in the mode of condensing such steam or vapour. Dated September 28th, 1831.

To William Hale of Colchester, in the county of Essex, machinist, for improvements in machinery, or apparatus for propelling vessels, which improvements are also applicable for raising or forcing fluids. Dated October 13th, 1831.

To Arthur Howe Holdsworth, of Dartmouth, in the county of Devon, esq., for improvements in the construction of rudders, and in the application of the same to certain descriptions of ships and vessels. Dated November 19th, 1831.

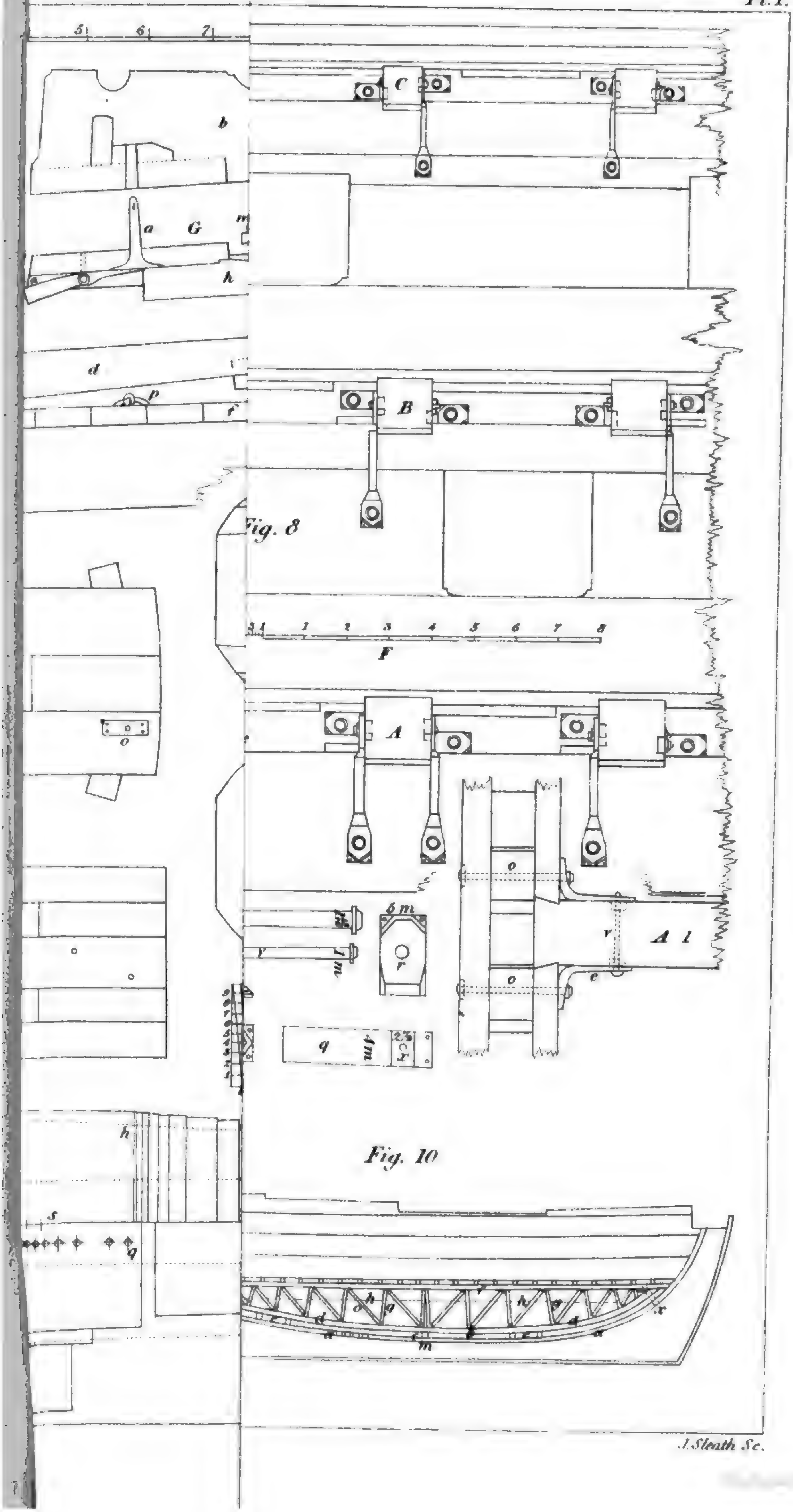
Extracts from Specifications, and Remarks.

Extracts from the Specification of Mr. Jeffrey Shore's Improvement on Tackle and other Hooks, which he denominates the "Self-relieving Hooks."—My invention consists in the application of a weight to one end of a hook, whereby, so soon as the boat or other load is supported by other means, the weighted end causes the hook to be relieved or unhooked; but in order that my invention may be more readily understood and carried into effect, I will proceed to describe the drawing hereunto annexed.

Figure 21 represents a block with two sheaves, and fig. 22, a block with one sheave, and fig. 23 shows a side view to each, of which a hook, constructed according to my invention, is applied. Fig. 24 represents a hook to be used without a block. In each of these figures the same letters indicate similar parts: *a* being the hook, *b* the strap which descends below the block, *c* a pin passing through the strap *b* and the hook *a*, and thus acting as a fulcrum or axis on which the hook turns; *d* is a continuation of the hook beyond the pin *c*, and this part *d* is made more heavy, so that when the load which has been suspended by the hook becomes supported by some other means, the part *d* will descend, as shown by dotted lines, and cause the hook to be withdrawn or unhooked. I will now suppose a boat suspended by two of these hooks to the stern or quarter of a vessel, when, if it be desired that the boat should be lowered, all that will be necessary, will be to slacken away till the boat is on the water, and supported by it, when the hooks being no longer pressed upon by the weight of the boat, the parts *d* of the hooks will descend and withdraw the hooks, whereby the boat will be relieved from the hooks, and may be hauled alongside, and thus the difficulty and danger which are experienced in lowering the boat when the sea runs high are avoided, and the boat may be hoisted with much greater facility, for it will only be necessary to reeve the lines *e* attached to the point of the hooks through the ring-bolts and haul on, which will bring the hooks through the ring-bolts, when the boat will hang on the hooks, and may be hoisted; and these hooks may be made still more secure from unhooking, by taking a single turn with each of the lines *e* (see fig. 21) affixed to the point of the hook, and making a hitch round the projecting pin *d*; the hooks will be moused and perfectly secure from unhooking. These hooks may also be used as common hooks, by passing a line through in the hole of the part *d* of the hook, and by making the end *d* of the hook fast to the strap *b*.

Observations communicated by the Patentee.—The following observations may explain the use of this invention more fully. Suppose you are lowering a boat from the ship's quarter, and you are fearful of the head tackle coming unhooked, first you

will let the stern tackle unhook itself, and a man in the head of the boat will hold the line attached to the point of the hook in his hand, with one turn over the pin, until such time as the boat is in the water, then, by throwing off the hitch, the boat will be clear. In hoisting up boats, when you bring the boat alongside to hoist her up, you will reeve the line through the ring-bolt, and pull upon it, which will haul the hook into its place; then one turn round the pin mouses the hook, and makes it perfectly secure: you will thereby save the men's fingers from being jammed, and the boat from being dashed against the side of the ship, perhaps two or three times. To consider this hook in the most awkward situation, which is when used for the stern-boat, and you have a man overboard, the ship is going fast through the water—she goes so fast that the boat, when touching the water, before the weight is all off, goes astern of the ship faster than the hook falls; it will not then unhook itself in that case; the men in the boat should whip their hands round the fall, and their knees against the boat-side, and give her a shake towards the ship's stern; two inches will be enough, it will be sure to unhook. It will be evident from this explanation, that this hook cannot fail; and I may add, that in all cases in which they have been used at sea they have met with most decided approbation; to which purport I have certificates from officers both of the Royal and Mercantile navies.



J. Sleath Sc.